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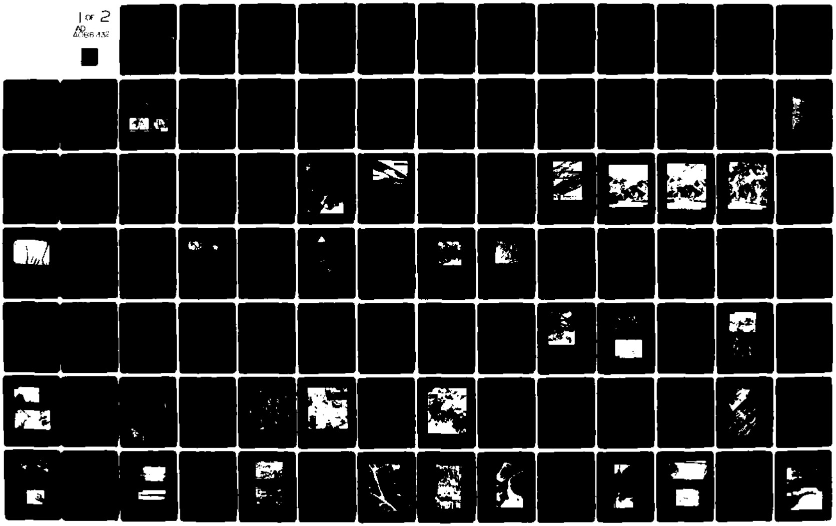

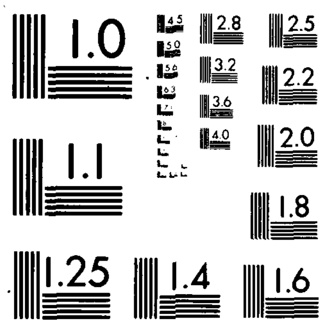

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MULTI-SOURCE IMAGE ANALYSIS

Radar, Thermal Infrared and Panchromatic Image Interpretation

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December 1979

Final Report

Approved for Public Release; Distribution Unlimited

Prepared for:
U.S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia

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19 REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 18 ETL-0208

2. GOVT ACCESSION NO.: AD-A086332

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): 6 MULTI-SOURCE IMAGE ANALYSIS.

5. TYPE OF REPORT & PERIOD COVERED: 9 Final Report,

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): Steller, David D.; Mel, Michael R.; Shiroma, Debra J.; Muir, William; Sowma, Julie A.

8. CONTRACT OR GRANT NUMBER(s): 15 DAAK70-78-C-0180 new

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Earth Science Consulting & Technology Corp.
3001 Red Hill Ave., Bldg. II, Suite 212
Costa Mesa, California 92626

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:

11. CONTROLLING OFFICE NAME AND ADDRESS:
U.S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060

12. REPORT DATE: 11 Dece[redacted]79

13. NUMBER OF PAGES: 163

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 166

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

10 David D./Steller Michael R./Mel
Debra J./Shiroma William/Muir
Julie A./Sowma

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Remote Sensing, Radar, Thermal Infrared, Panchromatic, Image Interpretation.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

For the purposes of this study, multi-source image analysis is defined as the utilization of imagery from panchromatic photography, radar and thermal infrared systems for providing military geographic information. The imagery was limited to sets available from a variety of governmental and commercial sources. Effort was made to obtain images from all three sensor systems, but at some test sites only one or two types were utilized. Sensor characteristics were evaluated in relationship to the targets of interest and sensor keys determined. Several useful enhancement techniques were utilized to emphasize feature parameters. (OVER)

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20.
Comparison interpretation using all three image types provided valuable complementary target information.

SUMMARY

Multi-source image analysis is an evaluation of remote sensor imagery for military geographic information. The imagery is confined to radar, thermal infrared and panchromatic photography. Image materials were obtained from a variety of governmental and commercial organizations. At each test site the objective was to gather all three image types. Although this effort was successful in many cases, at some localities only one or two image types were located. After a review of the various sensors involved, a series of targets were evaluated for a limited set of terrain analyses categories. This evaluation consisted of both standard image interpretation techniques and analog processing approaches. The distinct advantage of the multi-source approach becomes immediately apparent as the user notes the complementary way in which the interpretation results can be correlated. Target keys emerge and sensor advantages and disadvantages are emphasized. The panchromatic photography contains the most comprehensive target information in one image, but the disadvantages in a military operation (i.e., daylight collection requirement, relative cloud-free, and altitude restrictions) must be considered from an operational standpoint. The radiometric temperature information available from thermal infrared (TIR) imagery can provide invaluable military geographic information. The resolution and fairly rigid data collection requirements are restricting parameters. Radar has the distinct advantage of all-weather operation and unique depression angle and side-looking collection capability. The active nature of the transmitted signal, however, makes detection of the source energy a distinct military disadvantage. In each case where radar could be used, the necessary information requirements will have to be carefully weighed against the potential results of detection.

The military geographic information categories analyzed were limited to: vegetation, open water, relative ground moisture, swamps and marshes, urban areas, roads, railways, buildings, bridges, power lines and pipelines. These features were evaluated using essentially the information contained in the imagery itself. Besides the information on topographic maps and road maps, no background information was collected in most cases. Only at the southern California sites near the investigation home office were any field measurements taken. These measurements included radiometric-temperature measurements and evaluations of ground moisture and plant growth patterns and types. These collections were taken to show the advantages made available to the interpreter. In a military operation, however, often little or no in-situ background data collection may be possible. For this reason these measurements were kept at a minimum.

The imaging radar which was used in this study has an all-weather day or night versatility. The active nature of the radar refers to the fact that it supplies its own source of energy or illumination. The systems investigated had antenna fixed below the collecting aircraft (with the exception of SEASAT) and pointed to the side. Such systems are termed side-looking airborne radar, or SLAR, systems. They produce continuous strips of imagery depicting very large ground areas located adjacent to the aircraft flight

line. Imagery from both real aperture and synthetic aperture systems are interpreted for this report. Band designations include: Ka, X and L. The best resolution available was the X band radar, which has ten foot resolution. The features on radar imagery bear no direct relationship to their counterparts in the visible or thermal portions of the spectrum. Surfaces which appear rough in the visible form may be smooth as seen by radar.

Thermal infrared (TIR) imagery is a photographic or electronic record of the radiometric temperature of surface features when measured at specific wavelengths (3 to 5 and 8 to 14 micrometers). Features not visible to the human eye can be detected on TIR imagery. Some of military geographic information detectable includes the differences between asphalt and cement, building materials, hot and cold pipes, insulated and uninsulated buildings, grasses and trees, wet and dry ground, and hot and cold water. These are but some of the uses of TIR in terrain analysis evaluations. This knowledge gives the interpreter a definite advantage over using panchromatic and/or radar only. In an urban area in a cold climate it might be possible to determine which buildings are heated and potentially occupied from nighttime imagery. Likewise in a warm climate the air conditioning systems might provide similar information. At one of the engineering plants studied, an above-ground pipeline system was evaluated for the transport of heated materials. In addition, valve shut-off stations were easily detectable. Although many environmental parameters such as condensation and solar heating affect a TIR scanner's recorded temperature, careful image evaluation can be used to extract valuable military geographic information.

Panchromatic photographic interpretation continues to be the most common, useful and economic form of military geographic information. The spatial resolution and geometric fidelity provide the interpreter with an exceptional amount of information. Under the proper conditions of camera, film and flight parameters, it is possible to record more spatial detail on a photograph than one can see with the unaided eye. Inspection becomes possible with magnification devices. Since most data users are more familiar with photographs than with either TIR or radar, a natural advantage is built into their use. Some of the characteristics which can be estimated by means of panchromatic photographic interpretation include: landform, soil and texture, building materials, road construction conditions, and seasonal changes in vegetation. These many advantages are only enhanced by using panchromatic photographs with radar and TIR.

The overall interpretation of the subject images for military geographic information has proven the advantage of using more than one sensor type. Panchromatic photography continues to be the most useful stand alone sensor, but its data collection requirements could make it a military liability. TIR can be collected at night, and in a passive system this presents a definite advantage. In fact, the most useful TIR imagery for most users is collected at night to eliminate the masking effects of solar heating. Differences in emissive radiation of various materials allow the interpreter to distinguish between many ground features. Experience in interpretation is essential for this usage. The all-weather capability of radar is a definite advantage,

while the active sensor characteristic is a definite military disadvantage. The real time look capability is also available on many system. Image content and the user needs must be weighed against the military considerations when using radar.

Little of the imagery used was collected simultaneously, so direct comparison was impossible when considering environmental parameters. In addition, little or no background information was available on the majority of the imagery relating to date, altitude, flight direction, time of day, etc. It would be a definite advantage for the interpreter to be able to control or know the exact data collecting specifications. It would then be possible to more thoroughly evaluate observed image characteristics such as seasonal and diurnal changes.

PREFACE

The Multi-Source Image Analysis report was produced with funds provided by the U.S. Army Engineer Topographic Laboratories (USAETL) under contract DAAK70-78-C-0180. This document presents imagery collected from numerous sources. Many persons were helpful and instrumental in collecting the material. These people are listed at the end of the INTRODUCTION. Every effort has been made to make the list complete, but the authors apologize to any source inadvertantly left out. The authors take full responsibility for all presentations, interpretations, and conclusions presented. Permission has been obtained and documented for the utilization of any copyright material used.

The USAETL contracting officer representatives were Lawrence P. Murphy from September 1978 to June 1979, and Joseph H. Kitrosser from June 1979 to completion. The authors are grateful for their cooperation, guidance, and review during the preparation of this report.

TABLE OF CONTENTS

TITLE	PAGE

LIST OF FIGURES

LIST OF TABLES

NOTE: (1) Image Source abbreviations given on Table 1, p. 18-19.

(2) Blank pages left intentionally to facilitate readability: 10, 20, 38, 52, 54, 63, 80, 97, 115, 120, 146, 152.

INTRODUCTION

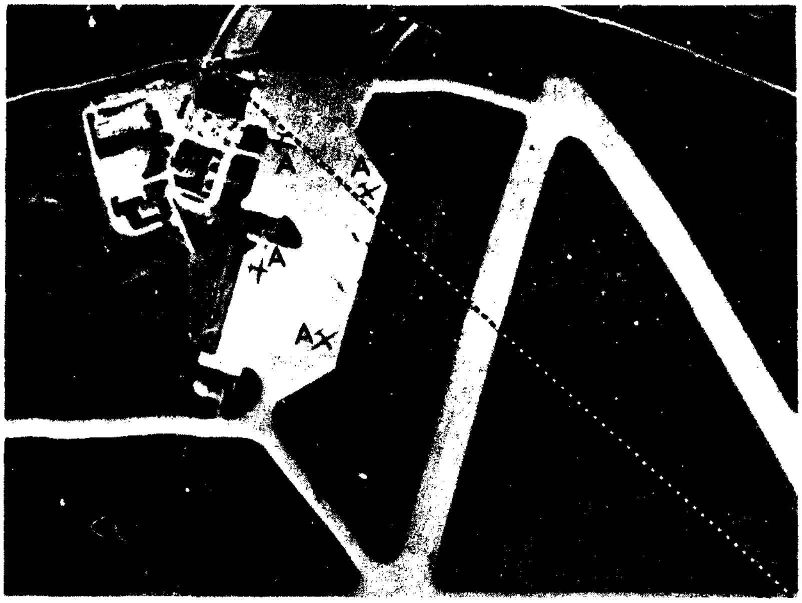
This report is designed to demonstrate the utilization of radar, thermal infrared (TIR), and panchromatic imagery in providing military geographic information. It documents the complementary features of each type of imagery under various conditions. Each type of sensor and the accompanying interpretation and enhancement techniques are evaluated. A number of examples collected from various sources are then presented. Simultaneous or near simultaneously collected imagery would eliminate or reduce the need to consider environmental and man-made changes resulting between data collection surveys. This was not possible. The sources of information came from a variety of governmental and private collections put together over a number of years. In many cases little or no historical knowledge was available on the data collection circumstances. For this study purpose the imagery was evaluated on content only with the few exceptions of those images with locally available information.

The evaluation of the imagery was based on established capabilities in the interpretation of remote sensor information. The report is meant to show the considerable advantages in using more than one of these sensors where possible as illustrated in the first Figure. This set of images of an airport in Schenectady, New York, is an example of the type of comparisons made throughout this report. Density analysis of these images follows. The reader will note that in a number of cases all three types of sensor information were not available. Having more than one type of sensor imagery has a definite advantage, mainly from the second look and added information viewpoint.

The operational and military considerations in collecting the three subject types of sensor data are important to this analysis. Radar stands alone as an all-weather sensor while panchromatic photography needs clear or relatively clear daylight conditions. Panchromatic photography is excellent for feature detail when it can be obtained. The collection of thermal infrared imagery can take place during the day or night in relatively cloud-free weather. Night conditions present the most advantages for many uses of TIR since the considerable affect of solar heating is reduced. Details available in panchromatic and TIR imagery certainly warrant their inclusion in a multi-sensor approach.

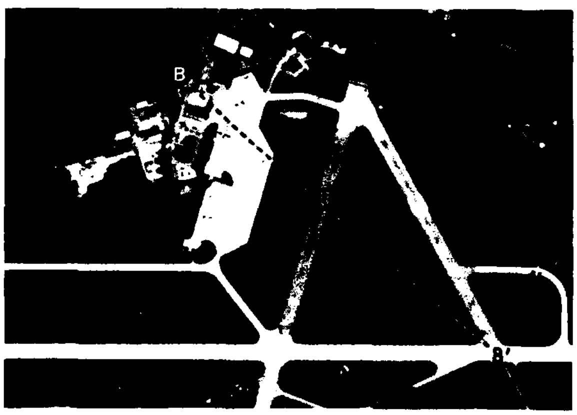
In addition to the environmental conditions necessary for successful image collection, the position of the collection platform (i.e., aircraft) is significant. The side looking airborne radar (SLAR) allows the data collection to take place at some angular distance away from the target of interest. For detail the thermal scanner must be fairly close depending on the resolution that is acceptable. Panchromatic photography, which requires daylight, can be collected either vertically or obliquely, but the clear weather requirement is certainly a drawback from a military standpoint. In this report vertical imagery only is considered.

The selection of the areas for study were based on the availability of sensor imagery. Sites were limited to the United States location. An effort was made to use examples from as wide a geographic area as possible. The analysts

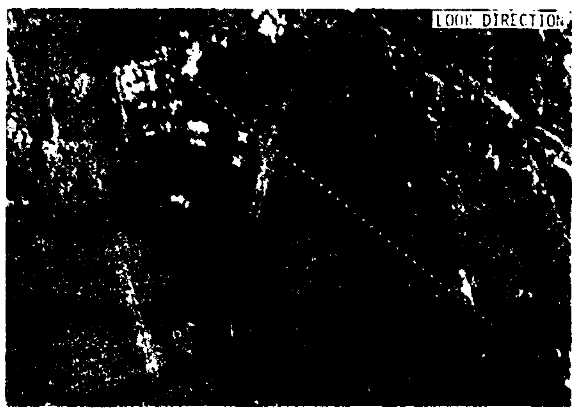


THERMAL INFRARED SCANNER (MAIRS), 19 SEP 72, RADC/IRRE.
NOTE WIND SHADOW BY AIRCRAFT AND HANGARS.

A--AIRCRAFT, P--AIRCRAFT PARKING, H--HANGAR, R--RUNWAY



PANCHROMATIC, 7 SEP 76, 1000' AMT.,
FILM 2402/CAMERA K-12, RADC/IRRE.



RADAR, UPD-10, 29 JUN 72
RADC/IRRE. LIKE POLARIZED.
LOOK DIRECTION INDICATED

FIGURE 1 -- SCHENECTADY, NEW YORK, CIVILIAN AND AIRGUARD AIRFIELD

Note: See Table 1 for source abbreviations p. 18-19.

trained in interpretation of remote sensor data evaluated imagery from the following categories: (a) vegetation, (b) open water, (c) relative ground moisture, (d) swamps and marshes, (e) urban areas, (f) roads, (g) railways, (h) buildings, (i) bridges, (j) power lines, and (k) pipelines. The evaluation of these categories was limited to background data easily available to the investigator. Some of the sites which were within easy driving distance of the study office (Costa Mesa, California) were visited in the field.

This report has been divided for ease of reading and understanding. The main body of the report covers the Image Analysis techniques and the conclusion and recommendations. The Appendices have numerous examples of image evaluation plus details of the sensors and interpretation identification keys. A glossary of terminology is also included to assist readers unfamiliar with words or definitions used in this report.

As the utilization and interpretation fields advance for radar, TIR, and panchromatic imagery, the user must continually re-evaluate the approach to fulfill program needs. The value of a multi-source approach is well documented, both in the enclosed examples and in the many available referenced publications.

Schenectady, New York, Image Analysis

The imagery of the Schenectady, New York (Figures 1 and 2), Civilian and Airguard Airfield, which is an example of the image analysis, was collected and provided by the Rome Air Development Center RADC/IRRE Griffiss Air Force Base, New York. The thermal infrared scanner imagery and the panchromatic photography was collected in September 1972 and 1976, respectively, while the radar (X-band-like polarized) was collected in June 1972. The area covered at the airfield includes the runways, hangars, terminal and aircraft maintenance area. The lines across the images are the traces where density scans were taken. They are plotted on Figure 2.

The thermal infrared (TIR) scanner data was collected on a MAIRS scanner which is a modified Texas Instrument AAS-18 scanner. MAIRS indicates medium altitude infrared system. On this thermal imagery the contrast between the runway and taxiways, the maintenance and hangar buildings and the surrounding grass fields is shown in detail. The major runway along the bottom of each image is concrete while the two A-shaped runways which meet at the top of the images are asphalt. The panchromatic image shows the signature of objects as reflected light from the sun's incident energy. Objects with high albedo (high reflectance) are bright on the image (paint on the runways, airplanes, metal roofs, etc.). Objects with lower albedos, such as grass or asphalt, produce darker signatures. Frequency components of grass cause transition and deflection of the returned image. As can be seen on Figure 2 (line B-B' -- Panchromatic photography density curve) the darker the signature the lower the albedo, the higher the film density. The film densities were measured on a Joyce Loebl film densitometer. The newly paved areas in front of the hangars also show a definite change in signature and film density.

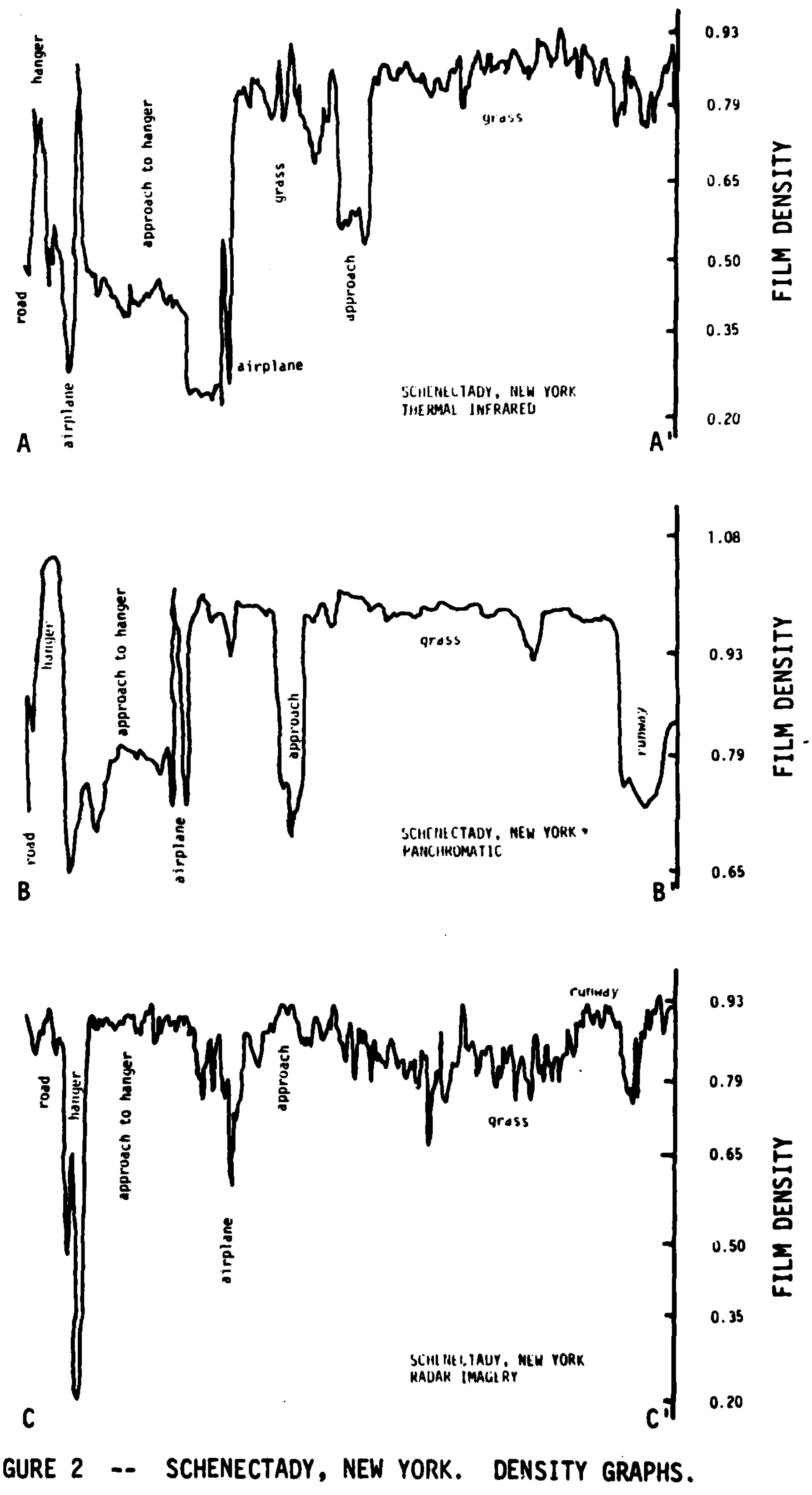


FIGURE 2 -- SCHENECTADY, NEW YORK. DENSITY GRAPHS.

On the thermal infrared image, the radiant heat differences are indicated by the differences in film density (A-A' on Figure 2). The darker density represents this relatively cooler object while the lighter densities represent the relatively warmer objects. The varying temperature enhances the actual physical characteristic of an object and produces a pictorial image. An obvious example is the parking apron in front of the hangars and the numerous metal aircraft. The metal is highly reflective and produces the cool (dark) patterns while the parking apron is asphalt. It has a rough textured surface and it retains a great deal of solar heat. Its signature is relatively warmer than the aircraft. An interesting feature are the two empty parking spots where the shape of aircraft appear. The aircraft have departed but the shadow cast from the aircraft cooled a "signature" of their shape on the apron. This cool spot has not come to thermal equilibrium with the surrounding asphalt so one can tell that an airplane was parked there.

On the radar image (graph C-C' on Figure 2) the film density differences are much lower with the exception of the large spikes or peaks indicating high radar reflectance. These peaks are caused by the aircraft, hangar buildings and cars, which are all metal. One aircraft is on the runway. The specular or dark pattern of the runway is the location of little or no radar return. This pattern contrasts with the mixed return that the grass produces. Many of these features can be easily picked off the density profile along line C-C'.

Image Location Index and Sources

The imagery used in this report is indexed in Figures 3 and 4. Figure 3 illustrates the sites in the continental United States and Figure 4 the California sites. Table 1 provides the sources of imagery and their abbreviations, which are used throughout this report.

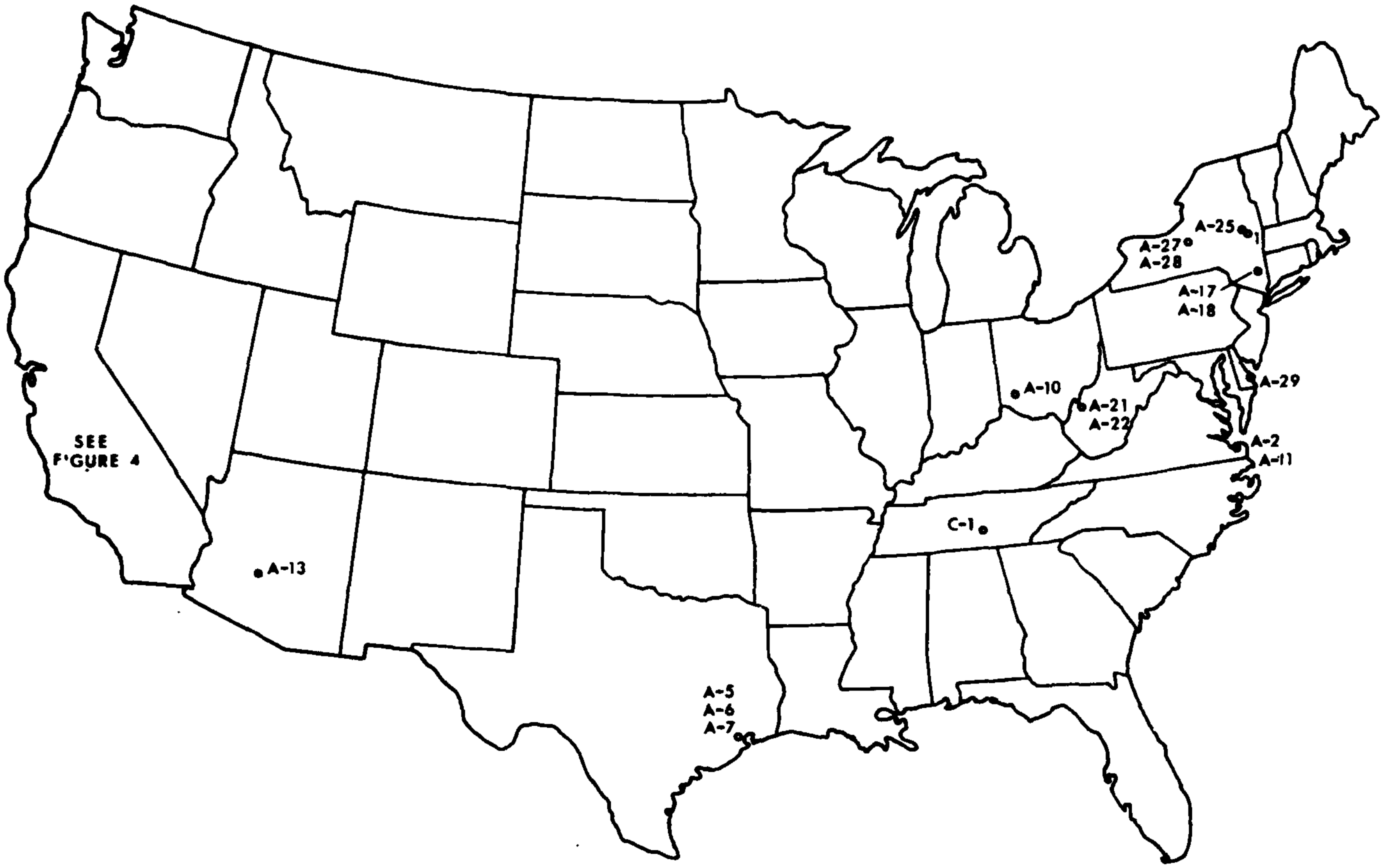


FIGURE 3 -- INDEX MAP, UNITED STATES. NUMBERED DOTS INDICATE LOCATION OF FIGURES

FIGURE 4 -- INDEX MAP, CALIFORNIA. NUMBERED DOTS INDICATE LOCATION OF FIGURES

SOURCE	ABBREVIATION	CONTACT	MATERIAL
NASA/JSC Houston, Texas 77058	NASA/JSC	R. Bratton	Panchromatic, Radar (X-Band)
Goodyear Aerospace Corp. Arizona Division Litchfield Park, Arizona 85340	GY	C. A. Anderson	X-Band Radar Imagery
Southern Virginia Planning District No. 16, Koger Executive Center Suite 100 Norfolk, Virginia	SVPD	Rob Jacobs	Panchromatic (Norfolk, Va.)
Air Photo Co., Inc. 2632 Bayshore Frontage Rd. Mountain View, California 94043	APC		Panchromatic (San Francisco)
Teledyne Geotronics 725 E. 3rd Street Long Beach, California 90802	TG		Panchromatic (Southern Calif.)
Environmental Research Institute of Michigan P.O. Box 8618 Ann Arbor, Michigan 48107	ERIM	F. J. Thomson	Radar (X & L Band) TIR (9-11.4 μm) * Visual (0.48-0.53 μm) *
San Diego Gas & Electric Company P.O. Box 1831 San Diego, California 92112	SDGE	Dennis Parra	Thermal Infrared (San Diego County)
Rome Air Development Center Griffiss Air Force Base New York	RADC/IRRE (Intelligence Reconnaissance & Research Eval.)	E. Hicks	Radar Thermal IR Panchromatic
U.S. Army Corps of Engineers San Francisco District San Francisco, California	USACE/SF	D. Pirie	Radar Panchromatic TIR

* μm = milimicron

TABLE 1 -- SOURCES OF IMAGERY

SOURCE	ABBREVIATION	CONTACT	MATERIAL
Jet Propulsion Laboratory California Institute of Technology 4800 Oak Grove Drive Pasadena, California 91103	JPL	L. Bryan	Radar - Seasat
U.S. Army Engineering Topographic Laboratories Geographic Sciences Laboratory MGI Data Processing and Products Division Fort Belvoir, Virginia 22062	USAETL	P. Murphy J. Kitrosser	Maps, Panchromatic, Radar, Thermal IR
Motorola Aerial Remote Sensing Inc. 4350 E. Camelback Road Phoenix, Arizona 85018	MARS	Jim Lightcap	Radar
Westinghouse Imagery NASA/USC Houston, Texas 77058	W	R. Bratton	Ka Band Radar
Mead Technology Laboratories 3481 Dayton-Xenia Road Dayton, Ohio 45432	MTL	R. Lusk, Jr.	Thermal IR
Wilson-Baldwin Aerial Surveys 1914 West Clay Houston, Texas 77019	WBAS	Tony Baldwin	Panchromatic
Texas Instruments, Inc. P.O. Box 5621 Dallas, Texas 75222	TI	Bill Lancaster	Thermal Infrared

TABLE 1 (Continued)

IMAGE ANALYSIS

The features being emphasized in this study represent a selected set of terrain analysis subjects. Complementary information on the features from each type of sensor imagery was evaluated. The results of these evaluations are designed to assist the reader in determining utilization criterion. The features are limited to: vegetation, open water, relative ground moisture, swamps and marshes, urban areas, roads, railways, buildings, bridges, power lines and pipelines. A wide variety of parameters have an effect on the ability of the interpreter to evaluate these subjects using the imagery of interest (radar, thermal infrared and panchromatic). In the individual cases of the sensors they are discussed in some detail in the Appendix, along with a series of interpretations.

A brief description follows of each of the features of interest and the details emphasized:

a. <u>Vegetation</u>: an almost infinite variety of vegetation shows on the imagery but emphasis has been placed on the detection of wooded and scrub areas and the differentiation between deciduous and coniferous. Some basic film types like black and white infrared and color infrared that can be utilized for quick differentiation of vegetation categories are outside the scope of this report.

b. <u>Open Water</u>: although water itself is easily detectable, the sharp boundary between water and land is often a needed point of information. Water temperature differences can be interpreted on thermal infrared imagery.

c. <u>Relative ground moisture</u>: indicated by changes in spectral reflectance, vegetation modifications, emissitivity and dielectric constant. Useful in hydrology and trafficability analysis.

d. <u>Swamp and marshes</u>: a tract of low wet land with grasses and other vegetation. Travel is difficult and knowledge of higher firm ground is useful.

e. <u>Urban areas</u>: habitated areas which have been lumped to include commercial areas.

f. <u>Roads</u>: an open way used by vehicles. The surface materials, especially concrete and macadam are evaluated.

g. <u>Railways</u>: the tracks, trackways, sidings, and associated buildings used by trains.

h. <u>Buildings</u>: individual structures which can be differentiated depending on the imagery scale. Shape, size, construction materials and orientations are analyzed.

i. <u>Bridges</u>: the materials forming roadways or railways mainly over water bodies.

j. <u>Power lines</u>: the wire, support towers, and support facilities which carry electrical energy.

k. <u>Pipelines</u>: surface and buried pipes which cross the countryside carrying liquid and gaseous materials.

To evaluate the imagery the interpreter must be able to recognize the feature directly from the image or through inferences based on known knowledge. An example of this latter technique is the noting of pumping stations spaced periodically across the countryside and inferring that a buried pipeline runs underground between the stations. Further knowledge may be gained through knowledge of the pumps themselves as to the material in the pipeline (i.e., natural gas, water, crude oil, refined petroleum products). The detail to which this will be possible depends on a number of variables which are discussed throughout this report. A primary factor is the resolution of the imagery. Resolution is defined as the ability to distinguish closely spaced objects on an image or photography.

Some of the problems involved in identifying the features which are not directly related to sensor system characteristics include: image contrast, feature familiarity, texture, interpretation clues, signature and atmosphere attenuation. In evaluating image contrast one can think of the ratio between the feature and the background. An example is the differentiation of vegetation. When a low shrub is viewed from a distance against a grass background, it is often difficult or impossible to distinguish. In an arid area where sagebrush (of similar size) is found with little or no surrounding grass, a view or image from the same distance might easily distinguish the sage. The contrast ratio of the sage against a light sand background would make this possible.

Feature familiarity is another factor that can assist or stifle the interpreter. An example of the need for feature familiarity is in the differentiation of lineaments. Are they roads, railroads, geologic faults or canals? Under close observation, knowledge of feature characteristics or feature familiarity is a major asset to the interpreter. The texture of a feature is another key to the interpreter. The frequency of change and arrangement of the tones forms the texture. When marsh grass is exposed above water at low tide, a textural pattern change in the water surface makes the grass detectable. When the tide rises, however, the texture of the water surface may gradually approach the texture of water only, making interpretation of marsh grass more difficult to impossible.

Interpretation clues or keys are another factor in evaluation. The presence of vigorous vegetation along a strip of ground surrounded by less healthy or vigorous plants can be a clue to soil moisture. The soil itself may not be visible on the image, but the clues present the information needed. Taking this clue a step further, the interpreter may be able to determine if the moisture is coming from a natural seep, from a fault line, spring, or from

a man-made irrigation or piping system. The signature represents the variations in spectral reflectance or emittance which is used for feature identification. The signature will depend on the sensor involved.

Atmosphere Attenuation

The atmospheric path through which all radiation detected by remote sensors passes has a definite effect on the received signal. The path length will vary according to the sensor used. In aerial photography the path length of sunlight passes through the atmosphere and back to the camera. An airborne thermal sensor detects energy emitted directly from the objects on the earth. For the active radar system the effects of the atmosphere depend on the wavelength. The short wavelength radar like Ka band (.8 to 1.1 cm) is backscattered by rain, snow and sleet. This property is utilized in weather radar systems. The longer wavelength radar system like X band (2.4 to 3.8 cm) is backscattered only by the heaviest thunderstorms while L band (15 to 30 cm) band is essentially unaffected by precipitation. Here we want to mention that the atmosphere can profoundly affect the intensity and spectral composition of available radiation. The atmospheric parameters which are the prime mechanisms for these affects are absorption and scattering.

Atmospheric absorption results in the loss of energy available to the sensor. Solar radiation is absorbed by water vapor, ozone and carbon dioxide. These gases tend to absorb electromagnetic energy in specific wavelengths as seen in Figure 5.

Atmospheric scattering is unpredictable diffusion of radiation by particles in the atmosphere. Without going into details of the scatterers, two common types should be mentioned. Rayleigh scatter is common when radiation interacts with atmospheric molecules and other tiny particles that are much smaller in diameter than the wavelength of the interacting radiation. The Rayleigh scatter strongly affects short wavelengths since its effect is inversely proportional to the fourth power of wavelength. Another type of common scatters is Mie scatter. This exists when atmospheric particle diameters essentially equal the energy wavelengths being sensed. Mie scatter influences longer wavelengths to a greater degree than Rayleigh scatter. Water vapor and direct particles in the atmosphere are major causes of Mie scatter. The Infrared Handbook (Wolfe and Zissis 1978) has a good section on atmospheric scattering for those wanting a detailed analysis of the subject.

Target Signatures

Imagery provides information for examination and analysis in a graphics format. The combination of all the characteristics of a feature or target is the target signature. In interpretation one has to associate film characteristics to target features. The terminology and relationships to each type of image must be established. This is covered primarily in the individual sensor section in the Appendix. The meanings of various standard photo interpretation terms for objects must be modified when using radar and thermal infrared imagery. Such standard terms as slope, shadow, pattern, texture, size and tone must be carefully considered. Only size, shape and pattern have direct

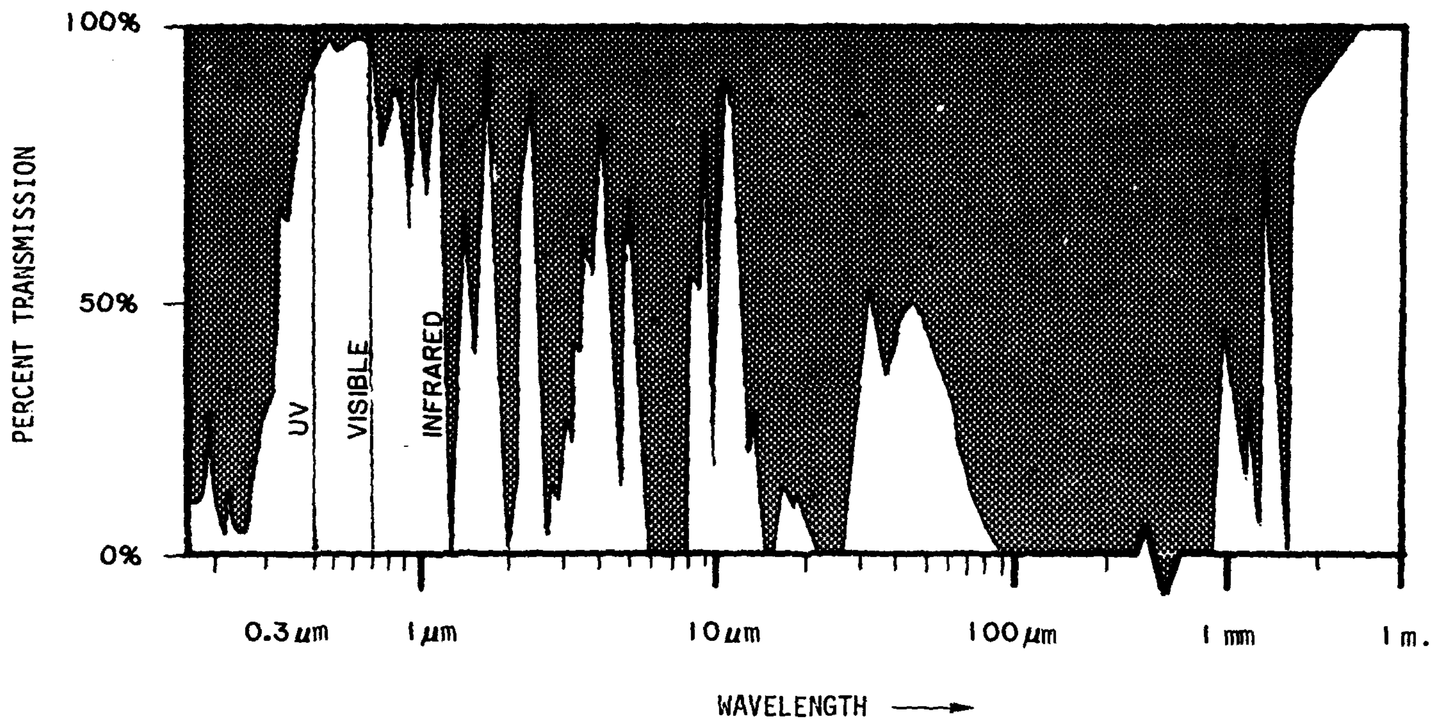


Figure 5 -- Atmospheric transmission at various wavelengths. Note that the horizontal axis is logarithmic.

parallels between radar and panchromatic interpretation. Texture, tone and shadow, which are all extremely useful in interpretation, are highly dependent upon the remote sensing system being employed. Often no direct parallel exists for these terms between normal air photo interpretation and radar or TIR image analysis. A short glossary (Appendix F) has been included to clarify some of these problems. A good reference for detail is the American Society of Photogrammetry Manual of Remote Sensing (1975).

The characteristic feature parameters which formulate the target signature are the criteria basis for identification and/or classification of image resident features. A knowledge of the target parameters and their significance to a particular target feature is a prerequisite to subjective, as well as quantitative, analysis. Table 2 (Attributes Affecting Imagery), Table 3 (Comparison of Elements of Interpretation), and Table 4 (Target Signatures) give an indication of target differences. The meaning and usefulness of these parameters are functions of the sensing system, recording media and technique as well as the physical attributes of the targets.

Seal Beach, California, Image Analysis

In determining the images of interest, the first criterion utilized was the features represented, then the availability of imagery. Seal Beach, California, has a wide variety of the features of interest. In addition, several sets of imagery from the site were available. This included thermal infrared collected by ESCA-Tech, radar collected by Westinghouse and Goodyear, and panchromatic photography collected by Geotronics. The overall area can be seen in detail on Figure 6, the panchromatic photograph. The area contains a military base (Seal Beach Naval Weapons Station), a wildlife refuge (Seal Beach National Wildlife Refuge), and the City of Seal Beach.

The Pacific Coast Highway Bridge located in Seal Beach, California, was evaluated in detail using available imagery and in-field investigation. The bridge is constructed of concrete. The roadway leading up to the bridge is constructed with asphalt. An evaluation of the thermal properties of the materials has resulted in details of the emitted energy at this site. The bridge is located adjacent to the U.S. Wildlife Refuge. The thermal image of this site (Figure 7) was collected about 1130 on 18 April 1972 and shows the difference in the thermal emittance from the two basic materials in question. The asphalt is darker than the concrete and indicates a higher amount of energy in terms of radiant energy reaching the overhead scanner. The lighter tones on the concrete represent relatively less radiant energy, which in most cases can be related to surface temperature. All of the objects seen in this scan are emitting energy or glowing because of their temperature. The differences in this emittance cause the various shades of gray seen on the TIR image.

To evaluate the effects of the roadway materials, a precise set of radiant temperature measurements were taken over a diurnal period (Figure 8). The measurements were taken at A1 (Asphalt 1) and C1 (Concrete 1). Although the scanner image was collected at a different time than the ground survey, the materials are the same as confirmed by aerial photography. The asphalt, which is black, has a much higher emitted heat than the white concrete. This

FEATURE	ATTRIBUTES AFFECTING IMAGERY		
	PANCHROMATIC	TIR	RADAR
Open Water	Turbidity, depth, sun angle, sea state	Emittance patterns, suspended materials, current patterns	Sea state, specular target
Ground Moisture	Soil, Spectral Return, Growth patterns	Surface temperature, Cooler signature	Dielectric Property difference
Swamps and Marshes	Vegetation types, water depth, tide	Vegetative cover water temperature, land-water boundary	Vegetation pattern interspersed by specular water
Vegetation	Physiognamy, Plant type, growth phase	Leaf structure, vegetative cover, phenological condition	Leaf structure, vegetative cover, physiognamy
Roads	Construction material, lineation, associated geographic patterns	Construction material radiant temperature difference	Construction materials, surface roughness
Bridges	Construction material shadows, associated water or land patterns	Construction material	Geometry, Construction material, corner reflectors
Railroads	Linear geometry, dual rail and ties, cross-country format	Road bed, pattern, metal emissivity	Metal tracks (corner reflector)
Powerlines	Cleared of vegetation, pole shadow, power line roads	Cleared of vegetation, metal tower emittance	Towers (corner reflectors) linear pattern of wire
Pipelines	Soil color anomaly, assoc. pumps and surface equipment	Thermal anomaly from soil disturbance, emittance from surface pipe	Metallic pumping station pipes and support facilities
Urban Areas	Land use, materials, civilization pattern	Construction materials, building emittance patterns	Land use, building orientation, construction material
Buildings	Materials, orientation, size and color	Emittance of materials, Orientation relative to solar heating	Construction material, orientation, dielectric properties

TABLE 2 -- ATTRIBUTES AFFECTING IMAGERY

	PANCHROMATIC	TIR	RADAR
Size, Scale	Dependent on altitude and focal length	Dependent on altitude	Dependent on altitude
Shape	Minor distortions due to topographic and radial displacement for large features	Sinusoidal distortion across imagery due to scanning geometry. May be severe for linear features	Less severe sinusoidal distortion
Resolution	Function of film type, lense quality, image scale, and atmospheric haze	Function of detector type, system settings, atmospheric conditions, and altitude	Function of system factors, altitude
Shadow	Result of sun angle	Usually none except in daytime images	Due to incidence an angle of beam. Important interpretive element
Tone	Produced by spectral reflectance of features in visible wavelengths	Produced by temperature and emissivity of features	Produced by material and geometry of features
Texture	Function of features, shape, size, pattern, shadow and tone	Depends on feature and its radiant temperature pattern	Interrelationship of radar band and surface roughness and materials

TABLE 3 -- COMPARISON OF ELEMENTS OF INTERPRETATION

TARGET	OBJECTIVE	SENSOR/SIGNATURE ANALYSIS*	REFERENCE
Water	Sea state	Pan - Glitter patterns show calm areas TIR - N/A Radar - Sensitive to surface roughness	U.S. *Army Corps of* Engineering, 1972
	Depth	Pan - May have depth penetration TIR - N/A Radar - N/A	Conrad, et al., 1968; Terwinkel, 1963; Joering, 1969; Lundahl, 1948
	Surface area	Pan - Variable results TIR - Thermal contrast with land Radar - Water acts as specular reflector. Appears black on imagery.	Simpson, 1969; Burgess, 1967, 1971
	Temperature	Pan - N/A TIR - Good discrimination based on tone Radar - N/A	
	Springs	Pan - May show vegetation anomoly TIR - Cool spot on daytime, warm on nighttime imagery Radar - May show vegetation anomoly	Guglielminetti, et al. 1975; Lee, 1969
	Ice	Pan - Stereo coverage useful TIR - Disturbances s subject to sharp thermal contrast with rest of ice sheet. Radar - Good sensitivity to surface roughness for I.D. of ice types.	Anderson, 1970; Poulin, 1973; Guinard, 1969
Bridges	Detection	Pan - May be studied in detail with proper scale stereo coverage TIR - May aid in determining construction materials Radar - Very obvious against a water background	
Powerlines	Detection	Pan - May often be detected because of vegetation clearing along right-of-way TIR - N/A Radar - Towers very obvious except against very bright background	
Roads	Detection, Materials	Pan - Easily mapped. Large scale facilitates ID of materials TIR - May often be detected as linear thermal anomolies at night. Good aid to material ID Radar - Often appear as dark (specular) surfaces	Vogel, et al., 1972
Buildings	Detection/ Function Identification	Pan - Interpretation detailed controlled by image scale TIR - Depends on setting and scale Radar - Depends on setting and scale	Vogel, et al., 1972

TABLE 4 -- TARGET SIGNATURE

TARGET	OBJECTIVE	SENSOR/SIGNATURE ANALYSIS*	REFERENCE
Vegetation	Structure, Type	Pan - Stereo coverage useful. TIR - May show minor tonal differences between communities Radar - Fair to good discrimination, depending on setting.	Spurr, 1948; Howard, 1970; Northrop and Johnson, 1970; (Batlivala, et al., 1976) (Bush & Ulaby, 1975) Drake, et al., 1974; Philipson & Liang, 1975
	Coverage/Density	Pan - Stereo coverage useful TIR - N/A, except in specialized settings Radar - High resolution sensors may show differences in certain vegetation types	Avery, 1968; Attema, 1974; Van Bandat, 1962
	Floristic Composition	Pan - High resolution, large scale, and local knowledge required. TIR - N/A Radar - N/A	Heller, et. al., 1964; (Kalensky & Wilson, 1975)
Soil Moisture	Amount	Pan - Some tonal variation, but not quantifiable TIR - High moisture may produce tonal anomoly Radar - Research indicates good potential	Batlivala & Ulaby, 1975; Blanchard, et al., 1974; Ulaby, 1974; Ulaby, et al., 1975
Swamps and Marshes		See comments RE Vegetation and Water	
Railroads	Detection	Pan - Diagnostic size, geometry TIR - Difficult to resolve except on low altitude, large scale imagery Radar - Good detection of tracks against dark background	
Pipelines	Detection at surface	Pan - May be identified or measured on large scale photos TIR - Temperature, nature of contents may be inferred on high resolution images Radar - Often appear as bright linears	
	Detection, sub-surface	Pan - May appear as linear tonal soil anomoly TIR - Same as above Radar - May detect pumping installations at surface, but difficult to verify	

*N/A indicates sensor not applicable to this problem

TABLE 4 (Continued)

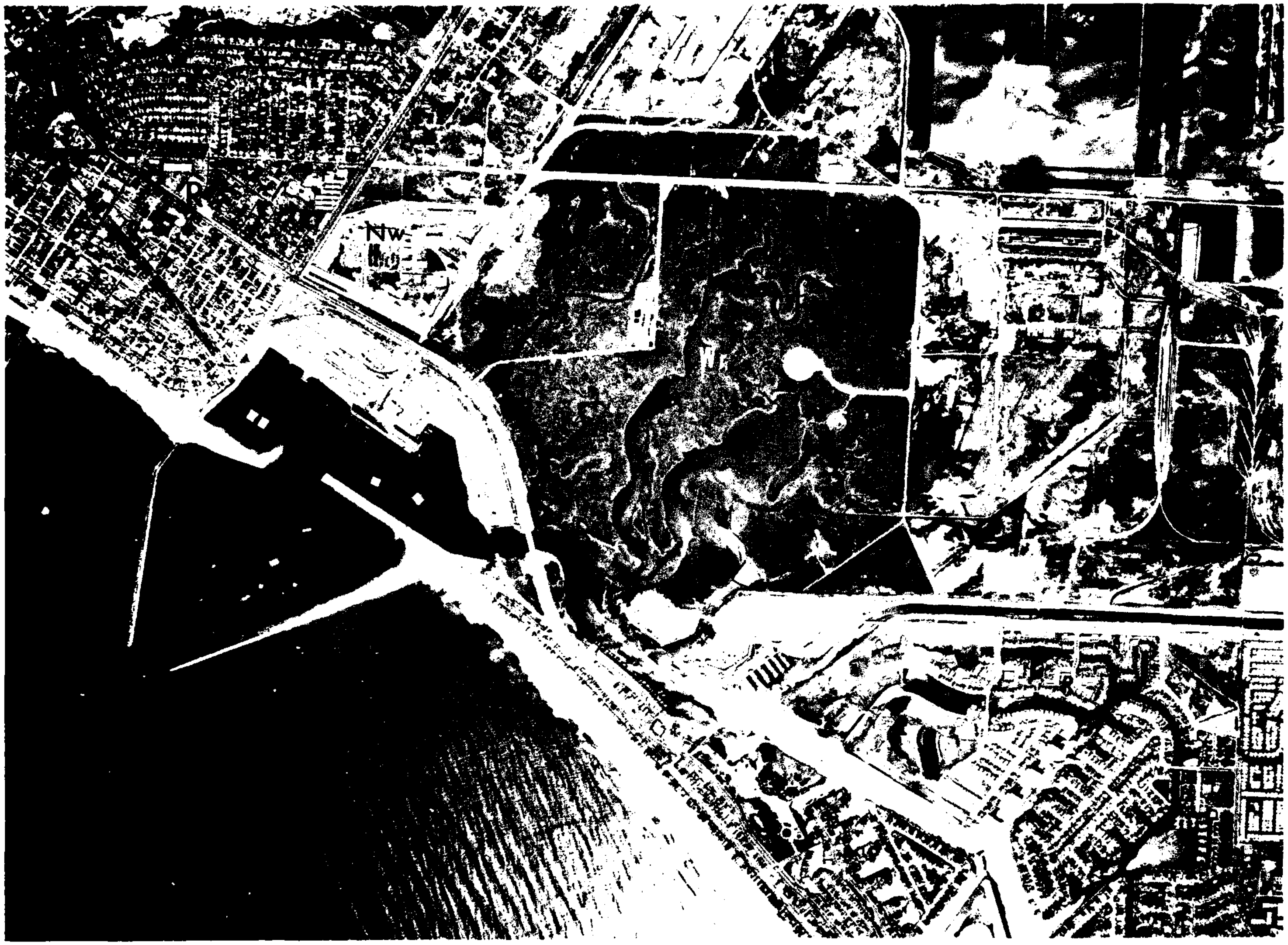
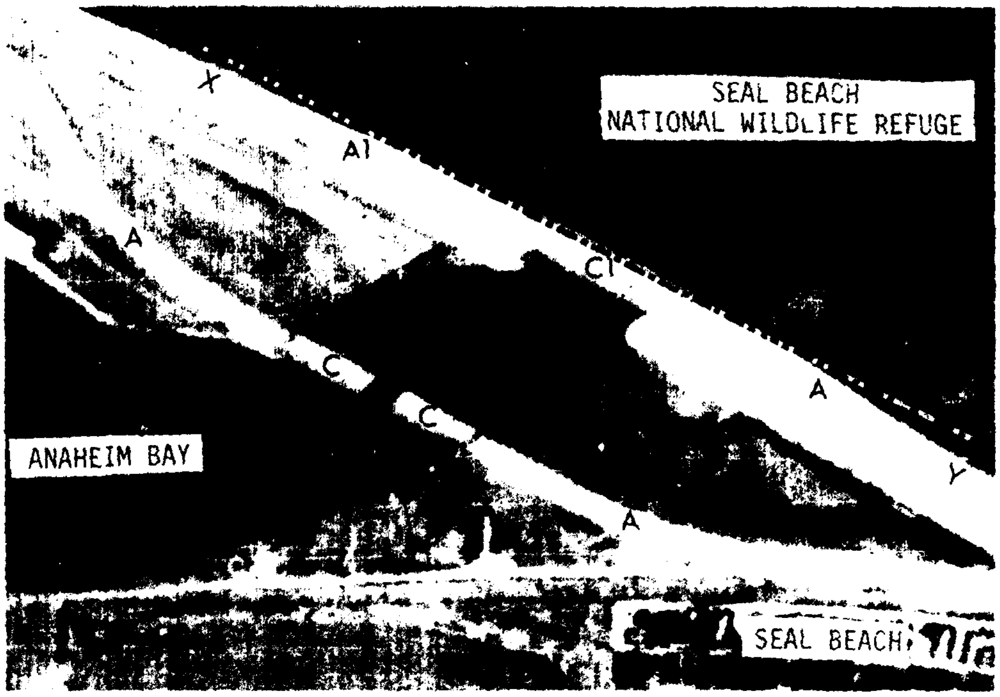
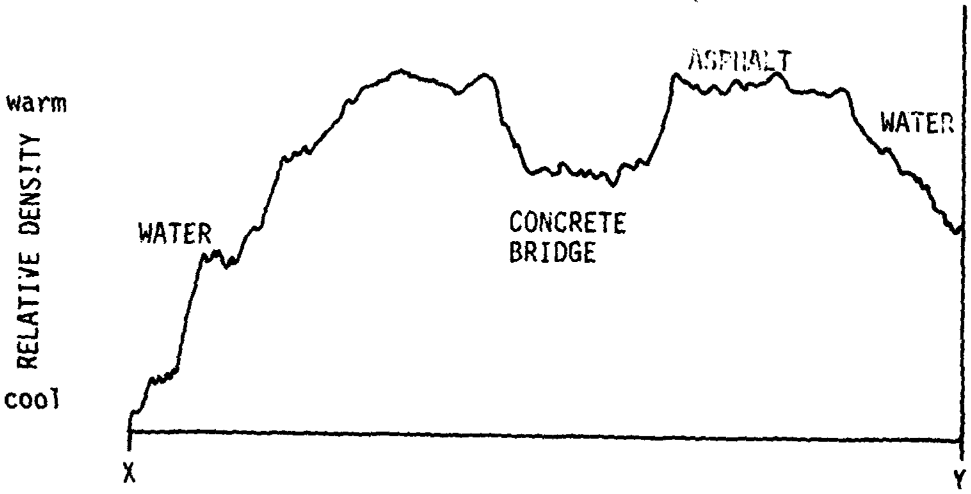


FIGURE 6 -- SEAL BEACH, CALIFORNIA. NAVAL BASE, PANCHROMATIC 18 MARCH 77, GEOTRONICS.
LEGEND: H = HARBOR, Wr = WILDLIFE PERSERVE, Nw = NAVAL WEAPONS STATION.



THERMAL INFRARED (8-14 MICROMETERS), BENDIX SCANNER, 18 APR 72.
1000' AMT, ESCA-TECH CORPORATION

A--ASPHALT, C--CONCRETE



THERMAL INFRARED DENSITY PROFILE, SAME IMAGE AS ABOVE.
DATACOLOR IMAGE ENHANCEMENT

FIGURE 7 -- SEAL BEACH, CALIFORNIA. PACIFIC COAST HIGHWAY BRIDGE

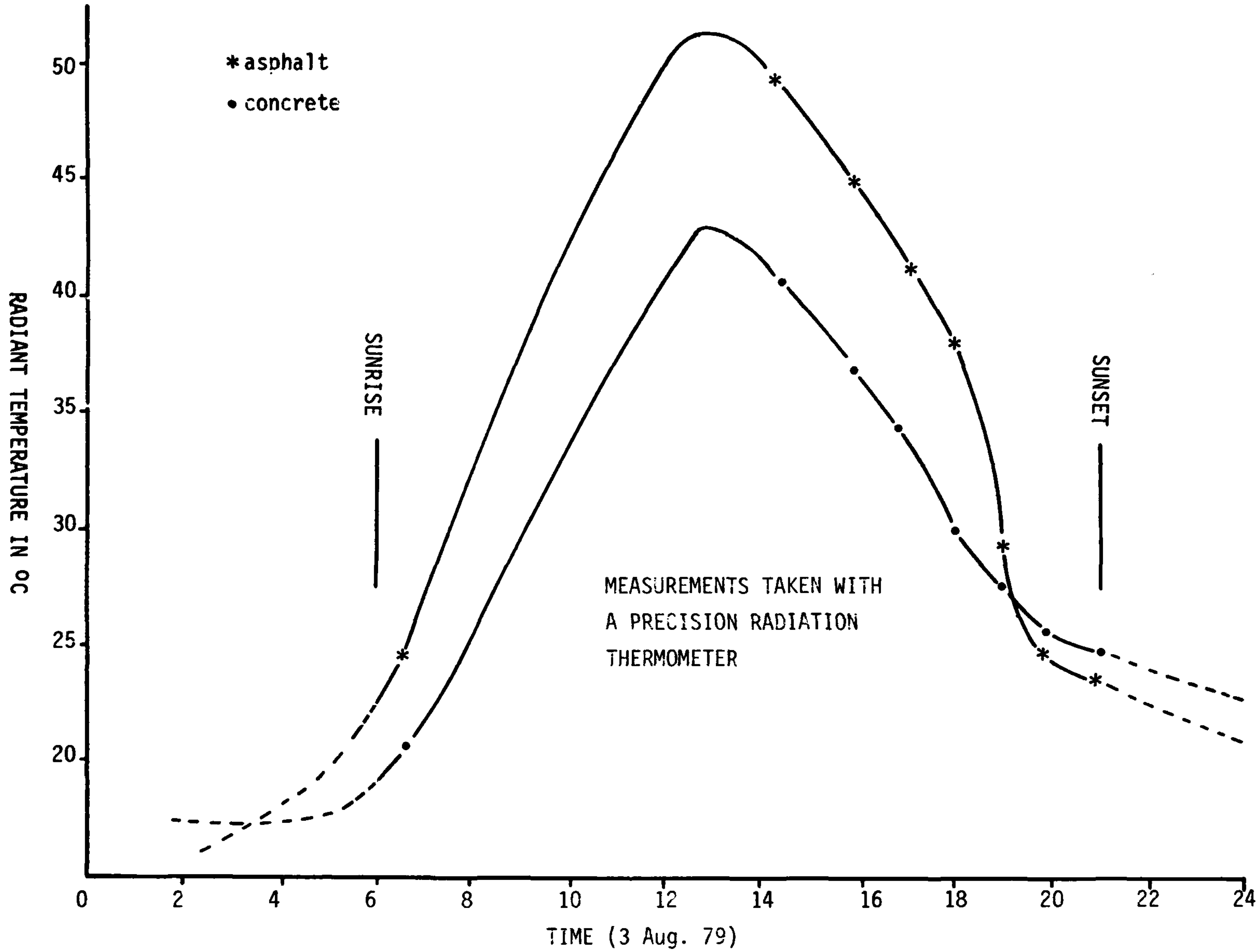


FIGURE 8 -- RADIANT TEMPERATURE MEASUREMENTS. PACIFIC COAST HIGHWAY BRIDGE

characteristic stays about the same throughout the day until sunset. At that point the asphalt cools off faster than the concrete. The emitted radiant energy of the asphalt is higher during the day and lower during the night than the adjacent concrete. This fact must be taken into account when interpreting surface road conditions from thermal infrared images. Figure 9 shows the density differences measured along the old bridge road.

A comparison of dual polarization images from Ka-band radar is shown in Figures 10 and 11 taken over Seal Beach, California, with the Westinghouse system. The HH image has generally stronger returns from most targets. This is true for the agricultural fields in the center, as well as the surrounding residential neighborhoods. There are a few features which produce a stronger return on the cross-polarized image. There appears to be greater tonal contrast in the HV image with a more interpretable balance between gray levels. This gives the impression of a greater information content in this image. However, it can be partly a product of electronic and photographic processing as opposed to actual differences in the radar signatures of the scene.

Depolarization of the radar beam, such as seen in the wildlife refuge, is believed to be due to multiple reflections from surface targets with complex geometry (Sabins 1973). Examples of features that cause strong depolarization are: shrub vegetation, marsh grass, and other objects with a large number of reflecting surfaces at varying orientations. In settings where the objects of interest do not include such features, like polarized images are generally superior. This is because there is a larger percentage of backscatter in this plane, and the signal requires less amplification, and therefore contains less electronic noise than cross polarized imagery. The cross polarized radar can indicate the vegetation and ground surface differences.

Figure 12 is an X-band SAR image of the same area shown in Goodyear radar imagery. In this figure, taken 12 years after the Westinghouse images (Figs. 9 & 10), a number of new towers are present at the navy base (upper right) near the bunkers. Also a good deal of urban expansion and marina construction is evident along the marsh area behind the main beach. The radar reflectance from the aquatic plant life in Seal Beach National Wildlife Preserve is variable. This signal depends on the volume of above-water vegetation and the tidal height. The higher reflectance appears to be from the areas with more above-water plant life while the areas with fewer above-water exposures image at a lower reflectance level (indicating less vegetation).

FIGURE 9 -- SEAL BEACH, CALIFORNIA DENSITOMETER ENHANCEMENT. DENSITY GRAPH OF PACIFIC COAST HIGHWAY BRIDGE, SEAL BEACH CALIFORNIA. TAKEN FROM THERMAL INFRARED IMAGE TO DEPICT RADIANT TEMPERATURE DIFFERENCES BETWEEN MATERIALS. THE GRAPH WAS MADE ON A SPATIAL DATA DENSITOMETER.

LEGEND
A - ASPHALT
C - CONCRETE

FIGURE 10 -- SEAL BEACH, CALIFORNIA. Ka-BAND SLAR, LIKE POLARIZED 4 NOV 65, WESTINGHOUSE/NASA.

LEGEND - H - SHIP HARBOR, R - RESIDENTIAL, Wr - WILDLIFE REFUGE, Nw - NAVAL WEAPONS STATION, Wo - OPEN OCEAN

FIGURE 11 -- SEAL BEACH, CALIFORNIA, Ka-BAND SLAR, CROSS POLARIZED. 4 NOV 65, WESTINGHOUSE/NASA.

LEGEND: H - Ship Harbor, R - Residential, Wr - Wildlife Refuge, Nw - Naval Weapons Station, Wo - Open Ocean

FIGURE 12 -- SEAL BEACH CALIFORNIA, X BAND SAR, 25 FEB 77, GOODYEAR/NASA.

LEGEND - H - SHIP HARBOR, R - RESIDENTIAL, Wr - WILDLIFE REFUGE, Nw - NAVAL WEAPONS STATION, Wo - OPEN OCEAN

IMAGE ENHANCEMENT

A number of techniques have been developed for enhancing certain attributes of different types of imagery by both photographic and electronic processing. The basic objective of these methods is to highlight features present in the image in such a way as to make them more obvious to the human interpreter. Subtle features which might otherwise escape notice are reinforced and may be compared by both quantitative and qualitative means.

Density slicing is a means of isolating areas of uniform tonal characteristics using electronic equipment. A black and white image may be divided into discrete categories on the basis of their tone. Thus, all objects which are white, or nearly so, will fall into a single class, while all dark objects will fall into another. Sophisticated systems are capable of displaying each class in a different color so that a normal black and white image may be viewed as up to 32 color coded units, where each unit corresponds to specific shades of gray. If the density slices are very narrow (i.e., a very specific tone), then density contours may be displayed. These may resemble more familiar types of contours, such as elevation, and they show all points with a given film density. Unlike other types of contours, these may intersect and do not have to close upon themselves. Density slicing and contouring is useful for displaying the continuous variation in gray tones present in an image as a series of discrete units, and it facilitates comparison of non-adjacent portions of an image. It does not add any new information but the color display makes many features more obvious than a normal black and white presentation (Figure 9 shows a black and white enhancement).

Edge enhancement is a procedure for identifying areas where the tonal contrast between adjacent features is strong. Figure 13 illustrates an edge enhancement of a thermal IR image. All areas where the difference between the tones of two adjacent picture elements is greater than a specified amount are displayed as black or white, while areas with little contrast appear gray. This creates a pseudo three-dimensional effect because the juxtaposition of black and white resembles a shadowing effect. The orientation of these shadows has a psychological effect on the viewer's perception of relative relief. Viewed with the shadows falling towards the bottom of the page, most interpreters see the water surface as the lowest "elevation", while if the shadows are placed toward the top (invert the picture), the water surface is raised. Note the presence of bridges crossing the canals as they are enhanced against the water background.

The information added by edge enhancement has a number of applications for military geographic intelligence. It may be of particular use in conjunction with detection of linear features such as roads, pipelines, or railroads because the enhancement procedure produces an anomolous straight line signature which stands out clearly from the varying geometry of the background. Since most systems allow for variable degrees of enhancement, the threshold level of contrast necessary to produce the edge effect can be adjusted to produce the best subject to background contrast ratio.

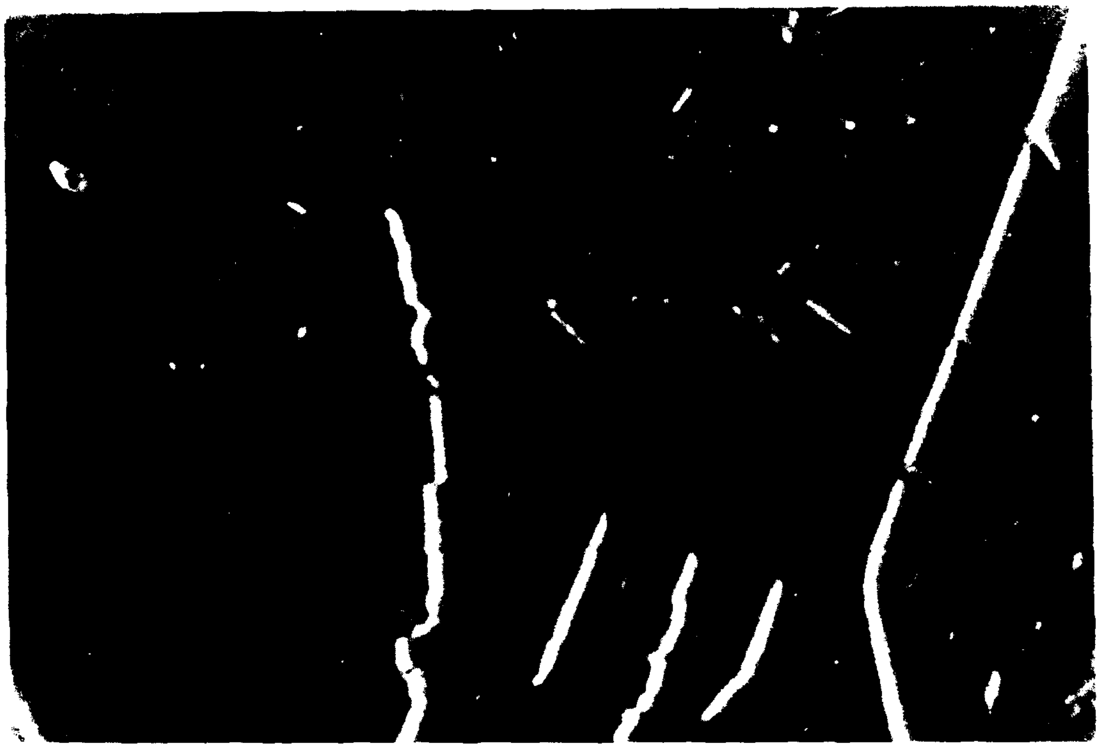


FIGURE 13 -- EDGE ENHANCEMENT OF A TIR IMAGE OF THE LONG BEACH, CALIFORNIA, HARBOR AREA

Linear features are brought out by this technique, including bridges and roads. The upper half of the TIR image shown in Fig. A-16 has been edge enhanced in this illustration.

Image Digitization and Display

One method of enhancement and analysis involves converting an aerial image to digital format with a television-type camera interfaced to a digital computer. The television camera scans the image and stores it as a matrix of numbers, where each cell in the matrix corresponds to a small rectangular area of the picture. Each pixel (as the unit areas are known) is stored in the computer as a number, usually between 1 (dark) and 256 (bright).

The computer can manipulate the picture matrix in a number of ways. One method involves assigning all pixels within certain ranges to particular classes. For example, the entire range of gray tones can be refined into 16 classes, each encompassing a range of 16 separate gray level units. Then, the computer can print the image using a unique symbol for each of the 16 gray level classes.

This type of treatment is extremely useful for quantitative image evaluation, and may be used to great advantage with thermal infrared imagery. Objects whose radiometric temperatures are within certain ranges are assigned the same symbol, and precise comparisons of objects in different parts of a scene can be made with a high assurance of quantitative accuracy.

One limitation inherent in this approach is that the conversion of a picture to a digital matrix can reduce the amount of detail in the image. The camera "sees" one pixel at a time, and depending on the scale of the image and the format of the computer scan, a single pixel may integrate more than one feature. Detail is lost as dissimilar objects are digitized into single cells as the camera averages their gray tone. A solution to this is to use a close-up camera and produce very small pixels. However, this creates additional expense because a smaller area is covered by one digital matrix. Conversion of imagery to digital format is the basis for many advanced image processing techniques, and is an area of extremely active remote sensing research.

This process is illustrated by Figures 14 and 15, in which panchromatic and thermal infrared images of a major oil refinery are compared. Each was digitized into cells 55' x 55', and both images cover approximately 1 1/4 miles on each side. The entire scan includes over 14,000 cells, and each has been assigned to 1 of 16 discrete classes. The printout shows each cell represented by a single character, and the character set has been selected to simulate a gray scale. The brightest areas on the image are shown as white cells, while the darkest are printed black. These two images are calibrated so that a symbol represents the same tone on both printouts.

Despite the fact that the resolution of the two scans is identical, more detail is present in the panchromatic photo printout. Spatial resolution of the original images is the primary factor affecting detail in the printout. The photo resolution is approximately 1 foot, while the thermal image resolves only a 4-foot object. This produces fuzzy edges on many objects in the TIR image, so the transition from one character class to another on the computer

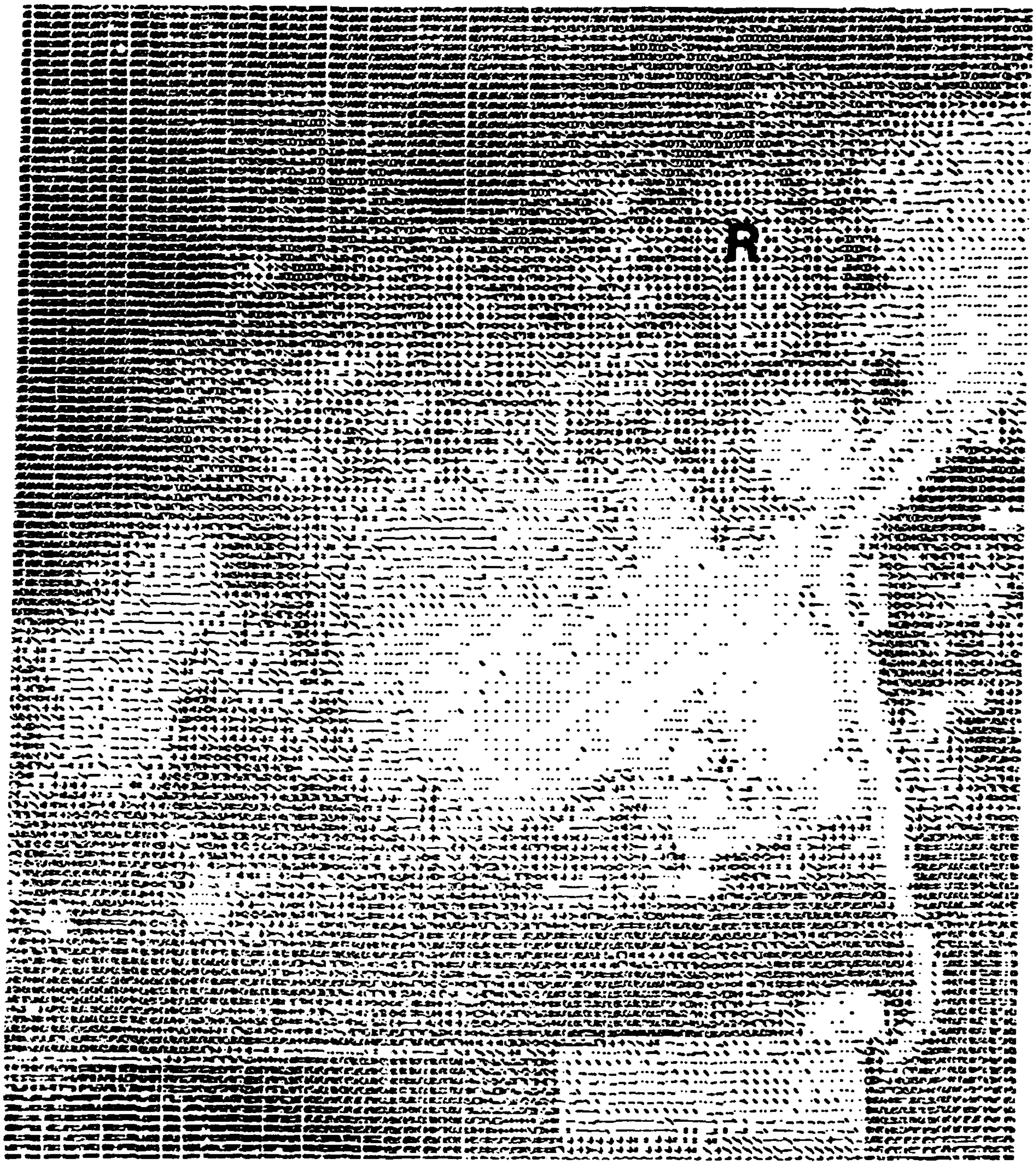


FIGURE 14 -- PRINTOUT OF DIGITIZED TIR IMAGE OF AN OIL REFINERY

The original image is shown in Figure 17.
The image was scanned diagonally. (Note Reservoir R)

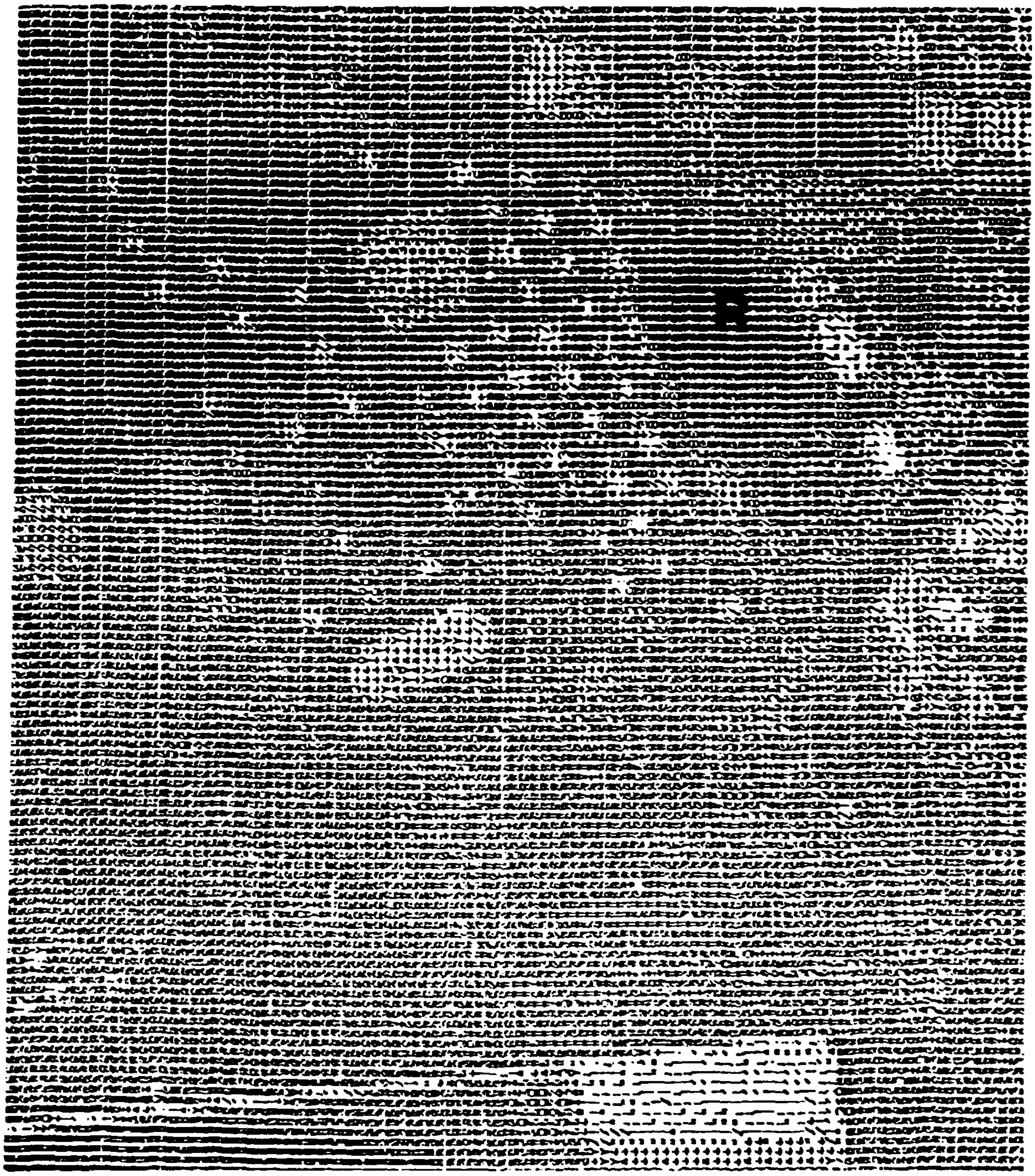


FIGURE 15 -- PRINTOUT OF A DIGITIZED PANCHROMATIC PHOTO OF THE SAME OIL REFINERY AS FIGURE 18

Note the superior detail, even though the digitized cells are the same size in both cases. The photo was scanned diagonally. (Note Reservoir R)

image encompasses a number of intermediate classes, and there is a gradation in the boundary between features with different temperatures. A second problem arises from the high temperature of many features in the refinery because these produce saturated signatures on the image. These white areas do not show any detail within, and are all included in the same class on the printout. These same features are resolved in the panchromatic photo with sharp detail, so their digital character display is much more clear.

Digital processing of thermal infrared data can be of particular use when applied to calibrated imagery. If temperatures of surface features are known at the time of the overflight, the modulation transfer function of the recording film can be used to derive the radiometric temperature of any object in the scene. Different objects identified on the character printout can be compared to determine relative temperatures, which is a great aid to quantitative interpretation.

Advanced methods of digital image processing can be used to improve the accuracy and meaningfulness of interpretatons. Although such methods are beyond the scope of the present effort, it is important to note such possibilities as multi-spectral correlation and classification, automatic change detection, and contrast enhancement.

Contrast Enhancement

In many images, the range of gray tones is significantly less than the possible range of the film sensitivity. This may occur for different reasons. For example, on thermal IR images, a scene may not contain a great range of temperatures, and consequently produces an image with a small range of indistinguishable gray tones.

There are both photographic and electronic means of changing the tonal distribution in any image. Figure 16 illustrates various approaches to contrast stretch by processing of digital image data (after Soha et al. 1976). The original distribution of brightness values may be rearranged to suit various purposes using a variety of mathematical techniques. The results of such treatment is an image which utilizes the entire range which can be exposed on black and white film, and may enable differentiation of subtle tonal variations. Each type of contrast enhancement brings out a certain tonal range, usually at the expense of another part of the range. For example, the linear contrast stretch saturates the extreme bright and dark features, but expands the range in between. A uniform distribution stretch is similar as it produces saturation at either tail of the distribution, but with good contrast in the middle. A Gaussian stretch provides good contrast at the tails of the range, with lower contrast at mid-range. Asymmetrical stretches may be used to bring out detail in a particular portion of thr range, as would be desirable for enhancement of low temperature targets on the TIR images.

Most techniques of contrast enhancement are more easily performed using digital computer image files than by photographic means. Computer enhancement

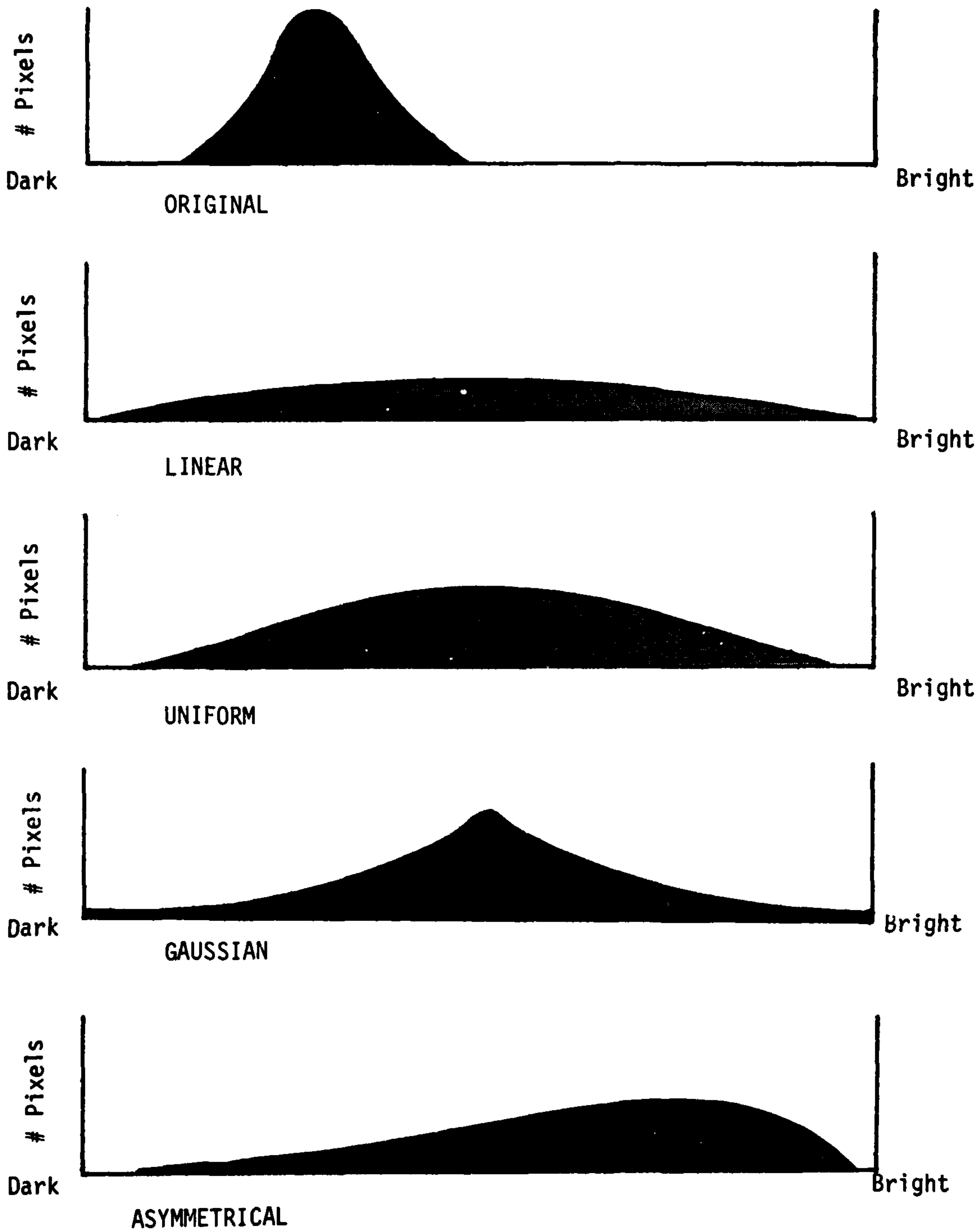


FIGURE 16 -- VARIOUS METHODS OF CONTRAST ENHANCEMENT

Each graph shows the number of pixels at each gray level. Actual digital processing would treat each level as a discrete value, rather than a continuous distribution.

is more precise and the results are more easily evaluated. Photographic methods do not allow the same degree of flexibility for matching the result to a particular tonal distribution model.

Wilmington, California, Oil Refinery

Nighttime thermal infrared imagery may be useful for analysis of industrial activities, as shown in Figure 17, which includes a major oil refinery, pipelines, railroads, and storage tanks. The brightest (hottest) spots in the image correspond to the large heating units used to heat crude oil for breakdown into various products. At least four separate units were operative at the time of the overflight. Within each of these no detail is visible because everything in these areas was hot enough to saturate the sensor, resulting in undifferentiated white tones. Smaller hot spots correspond to storage tanks which contain heated products of the refining process. These appear as white circular features, while empty tanks appear black. It is theorized that gray tanks contain unheated oil and gasoline. These have a heating effect on the top of the tanks seen by the scanner, and are warmer than those which are empty.

An intricate network of surface and underground pipelines conduct fluids throughout the refinery. Generally, the resolution of this image is insufficient to separate these objects. However, there are specific exceptions. These linear features which connect the heating units to the storage tanks are probably empty pipelines.

A panchromatic aerial photograph of the refinery is shown in Figure 18. Many features can be identified with greater accuracy and in greater detail on this photo, except for types of information which are temperature related. For example, using the photo it is not possible to locate or differentiate between tanks which contain oil and those that are empty, but the thermal image makes this obvious. The same is true for identifying surface pipelines which are actively conducting heated oil.

Most of the bridges, railroads, and pipelines which cross the river are visible in both images. In the photo, the water (dark) contrasts with the lighter signature at each span. In the thermal IR image, the contrasts are reversed because the water is relatively warm. Many of the pipelines which cross the river are not detectable because they contain heated oil, and thus produce the same image tone as the water surface. Only metal or concrete bridges and overpasses are sufficiently cool to produce a dark signature against the bright water background.

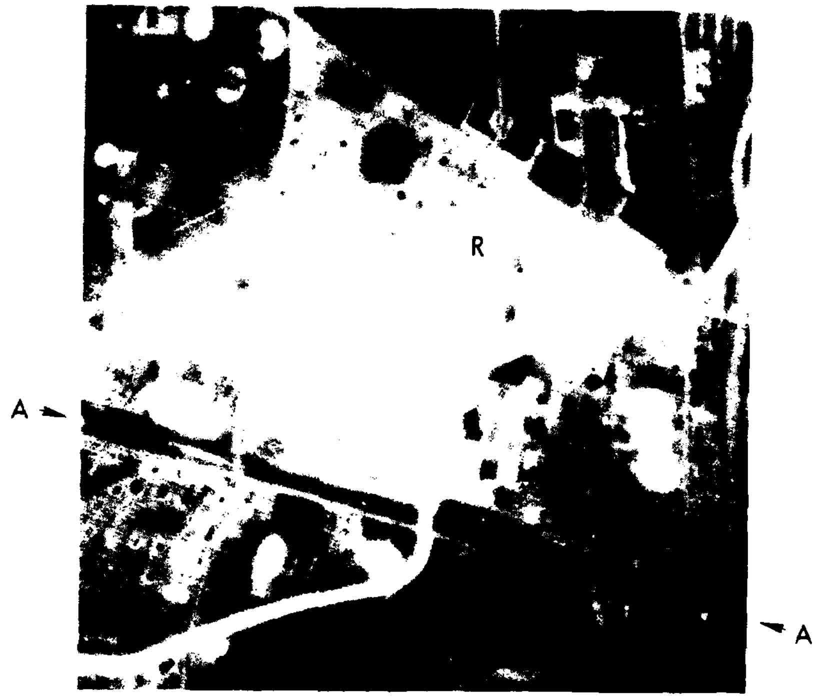


FIGURE 17 -- A NIGHTTIME THERMAL IR IMAGE OF A MAJOR OIL REFINERY IN WILMINGTON, CALIFORNIA. The lower portion illustrates a film density profile from A to A'. This generally corresponds to radiometric temperature. Compare with Figure 18. (Note Reservoir R)

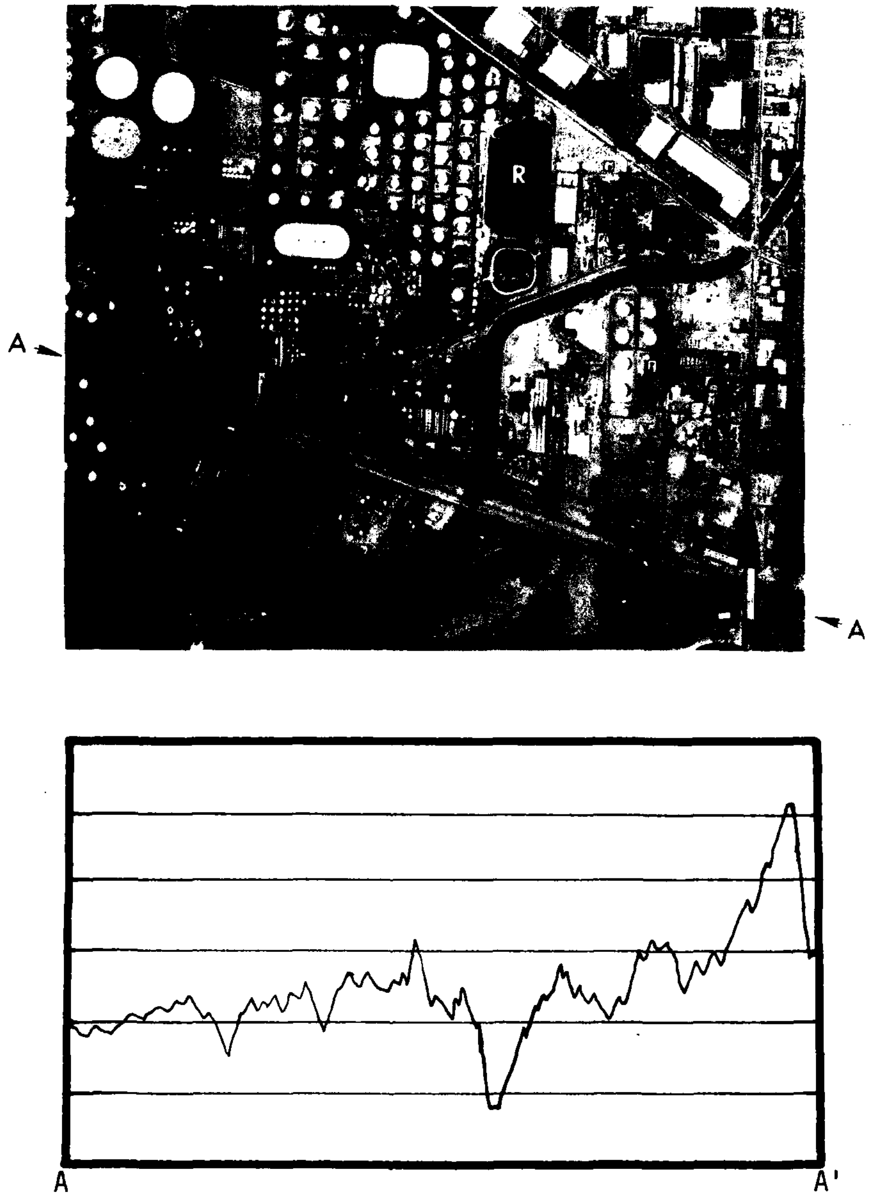


FIGURE 18 -- PANCHROMATIC PHOTOGRAPH OF THE SAME REFINERY AS SHOWN IN THE TIR IMAGE OF FIGURE 17.

Note that the area covered does not coincide with Fig. 17. due to distortion in the thermal image. Shown below is a film density profile between A and A', the same line shown for Figure 17. (Note Reservoir R)

CONCLUSIONS

1. The multi-source approach has the distinct advantage over a single sensor survey in the complementary way the interpreted results can be utilized. Under the proper conditions of camera, film, and flight parameters, it is possible to record more spatial detail on a photograph than can be seen with the unaided eye. Radar and thermal infrared (TIR) imagery can be used to collect information in other than perfect conditions. This is especially true of radar with its all-weather capability and sensitivity to metallic objects which are often of considerable military interest. TIR, which is often collected at night, has the valuable capability of differentiating materials based on their radiant temperature.

2. Radar is an active sensor with the all-weather capability. In a military situation, the transmitted signal can be detected with the appropriate electronic equipment. However, the data collection aircraft can use the camouflage of nighttime or inclement weather plus its speed for escaping detection. In addition, radar has the side-looking characteristic, the resolution and the real time capability which all add up to form an additional advantage. These advantages and disadvantages must be weighed against the military need and curcumstance.

3. Although the data collection parameters for thermal infrared imagery are restrictive (i.e., lower altitude for good resolution, lack of fog or clouds, time of day restriction for target differentiation) there are definite advantages. The passive sensor does not transmit a detectable signal. The radiant energy differences of targets can provide an experienced interpreter with useful material differentiation data. In the study of roads, urban areas, vegetation, water surfaces, etc., this adds a parameter not available on radar or pan imagery. When no ground information is available, however, the interpreter must be alert for changes in surface conditions which will change detected gray scales on the imagery. A roof top, for example, will image differently depending on dampness, wind condition, dirt and dust, scanner settings, and time of day.

4. Panchromatic photography still represents the greatest single source of target knowledge, if it can be obtained. The data collection conditions can be restrictive with the need for relatively clear weather, daylight, vertical access if possible, and often the need for low altitude. The images collected can be evaluated by a much wider group of interested personnel because of general knowledge on photographic evaluation. All of the features of interest in this study were identified on the panchromatic photography.

5. The lack of simultaneous or near simultaneously collected imagery, in most cases, caused an interpretation disadvantage in target comparison. Geographic and environmental conditions change, so direct comparison was often impossible. In most cases, the imagery

that was available was not closely documented. Dates, times, altitude, sensor characteristics, and target identification were often missing.

6. The approach presented here illustrates the distinct advantages in evaluating the subject terrain features with the multi-source approach. When conditions of weather and sensor configuration change in a military situation, an interpreter trained in the multisensor approach can easily adjust and still provide the necessary information. The analyst can also make clear recommendations as to the correct sensor packages under changing conditions.

7. The evaluation of panchromatic photography and TIR imagery together can be a definite advantage to the interpreter. For example, a surface pipeline, as shown on panchromatic photography, will image as a shade of gray depending on the available light and the pipe's color. When the interpreter views the same pipe on TIR imagery, he also notes a shade of gray, but in this case it represents the pipe's radiant temperature in relationship to the other features in the image. This information can often be used as an indicator of the material being transported in the pipe. This is especially true if the material is transported at other than ambient temperatures and the pipe is not insulated (i.e., steam, hot oil, freon). This type of information can be a great asset in evaluating an industrial or military installation. The same comparisons can be made when interpreting buildings, roads, water bodies, or soils.

8. Panchromatic photography and radar (X-Band is good because of the resolution) make a good combination for terrain analysis. Pan imagery presents the detailed resolution and identification parameters, while radar is all-weather and sidelooking. The photography can be used for detailed identification of features, such as soil type, vegetation identification, marsh delineation, and building material differentiation. The panchromatic photography usually covers a much smaller ground area than the radar imagery. This is often true if time and weather were problems during data collection. In such an example, the photography can be utilized as a calibration source for identifying features within the radar image which covers the much larger area. The radar, on the other hand, is especially sensitive to metallic objects (vehicles, trucks, planes, bridges, oil tanks and pipeline, utility facilities), which often represent the military targets of interest.

9. Radar and TIR imagery can be used in tandem to evaluate signals resulting from microwave and thermal portions of the spectrum, respectively. The radar will reflect smooth features like water, roadways, and runways in specular fashion, while metallic objects like bridges, buildings and powerline towers will image as bright signatures. The TIR will image each of these features according to their radiant temperatures. Often a roadway, for example, can be identified according to the emissivity properties of construction material on the TIR. The metallic features which image as bright

signals on radar are not easily differentiated on TIR in many cases. The boundaries of water features are usually easily differentiated on both radar and TIR. The radar response affords a markedly different view of the land surface when compared to the sensing of light or heat.

RECOMMENDATIONS

1. We recommend collecting a set of multi-source images in a controlled setting for evaluating military geographic parameters that have been obtained as close to simultaneously as possible to maximize sensor response and minimize the environmental changes. The most useful sensors include radar, thermal infrared, and panchromatic photography, along with any others which might be easily obtained. All imagery should be well documented for date, time, sensor, altitude, flight direction, and image processing techniques. Ground information should be collected during the overflights for later evaluation and calibration purposes.

2. The ground information is essential to this recommended study. In making the evaluation of the imagery that is collected, it will be possible,with ground surface information, to make exact interpretations. For this purpose, it will be necessary to collect radiation temperatures, ground moisture, temperature, humidity, and wind velocity. In addition, the ground team can identify building materials, rock and soil, and vegetation. It is often helpful for the ground teams to take hand-held photographs of collection sites so later comparisons can be made with the aerial imagery.

3. The sites used for such a demonstration would contain a variation of terrain and climatic conditions. An area with variable climate, slope, and vegetation conditions, combined with changes in soil moisture, should probably be considered for one locality. At such a site, vegetation characteristics can give significant clues to underlying soil and rock condition. For this reason color infrared (false color) photography, which is good for vegetation discrimination, should be considered along with the sensors. If possible, an arid site would also be useful. Slope and ground surface conditions become more important for trafficability purposes. The affect of rare rainy conditions can be significant when determining vehicle movement in such an area.

4. If the facilities and funds are available, the digital analyses of simultaneously-collected imagery would be most useful. This would allow the interpreter to manipulate the target signature data into a directly correlatable format, including scale, look direction, and distortion free image. The simultaneous nature of the imagery would make the imagery directly comparable without having to consider the transitory weather parameters.

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APPENDIX A

INTERPRETATION

Carlsbad, California

Thermal IR, SAR radar and panchromatic images of a portion of Carlsbad, California, are illustrated in Figure A-1. Carlsbad, California, is located approximately 35 miles northwest of San Diego, California, and 10 miles south of Camp Pendleton Marine Corps Base. The large body of water labeled "W" on each image represents the Agua Hedionda lagoon. East of the lagoon the area is primarily agricultural with a power plant located in the southeast corner of the image. West of the Agua Hedionda lagoon is Carlsbad, California.

Damp ground is labelled "Dg" on the three images. On the thermal IR image the damp groung "Dg" is expressed as a cool signature relative to the surrounding terrain. This signature is caused by the evaporation of the absorbed water on the surface of the fields, which keeps the area cooler both day and night. This is an evening image which is indicated by the higher temperature of the open water, W, relative to the land areas. The radar image represents the field "Dg" as a dark specular area while the panchromatic shows an agricultural field. The radar and panchromatic images give little information on the moisture content of the field.

Roads are well defined linear features on all three images, and with 10X magnification, cars and trucks can be distinguished on the panchromatic image. On the thermal IR image the roads and major highways express a warm signature relative to the surrounding roof tops and ground. The asphalt used to pave the highways has a high thermal capacity, that is the ability to store heat. This evening image illustrates that capacity.

The railroad labelled "rr" passes through the three images in a linear fashion similar to the roads. The railroad tracks can be mistaken for a highway or road on the panchromatic image but close observation reveals the tracks are much narrower than a road or highway, and the roads have observable cars on them. On the thermal IR image the tracks express a cooler signature than the adjacent highway since the metal has a low thermal capacity. The railroad on the radar image is expressed as a bright white line because of the high reflectance and corner reflectors along the metal tracks. The main highway paved with asphalt projects a black line across the image.

Buildings are recognizable on all three images and are labelled "b". In the panchromatic image, the vertical height is enhanced by shadowing. In the radar image buildings with metal roofs image bright white while the shingle roofs made of wood project gray to black. Within the thermal IR image the roofs signatures are cool relative to the road and adjacent ground. Because this TIR image was taken in the winter, it might be thought the roofs would have a warm signature due to the heating within the houses, but the cool signature of the roofs can be interpreted as evaporative cooling from the moisture or dew in the air, common to roofs in a coastal area and/or good insulation.

There are two types of bridges labelled on the images, "BH" for the highway bridges and "Br" for the railroad bridge. The panchromatic image outlines the bridges the best. For example, the railroad bridge and the bridge crossing the jetty labelled "J" have shadows which clearly express their height off the surface of the water. The bridges on the radar image are identified as bright spans across the specular signature of the background water. In the thermal IR image the bridges are identifiable where the road or tracks cross over the water, or where a road crosses over the main highway.

The pipeline labelled "pl" is located in the lower right corner of the panchromatic image. This area is an outlet for warm water being discharged from the electric power plant. The pipeline was identified by the stream of water moving in the direction of the arrow which has cut a path through the beach, and is travelling seaward, and has discontinued the breaking waves within that interval.

Elizabeth River (Eastern Branch), Norfolk, Virginia

The radar and panchromatic images of Figure A-2 show a westward look along the Eastern Branch, Elizabeth River. The bridge is the Norfolk and Western Railway Bridge leading from Chesapeake on the left to Norfolk on the right. The center span, which causes the sharp radar reflectance, is the area which is raised to allow ship traffic. It appears that the bridge can be lifted for larger water-borne vessels. A railroad siding near the industrial area (I) in Chesapeake contains a number of train cars. They are highly reflective. In viewing the panchromatic image of the area, it is noted that many of the train cars carry automobiles which have been offloaded. Just west of the dock (D) is another group of industrial buildings. The road near the dock is relatively flat and has a low radar return, but the roof area away from the dock has many vents and metal protrusions which cause a bright radar return. On the Norfolk side of the river the agricultural plots (A) give a mixed return. Several of the surrounding buildings are bright on radar. This, however, is limited to those perpendicular to the transmitted radar signal. In the urban areas which surround the industrial area, the radar signal is generally mixed. The return from deciduous trees surrounding the homes and the large grass-covered lots contribute to this mixed radar signal. The river water is specular and the land-water boundary is easily distinguished.

PANCHROMATIC, 15 JULY 75, TELEDYNE GEOTRONICS

LEGEND

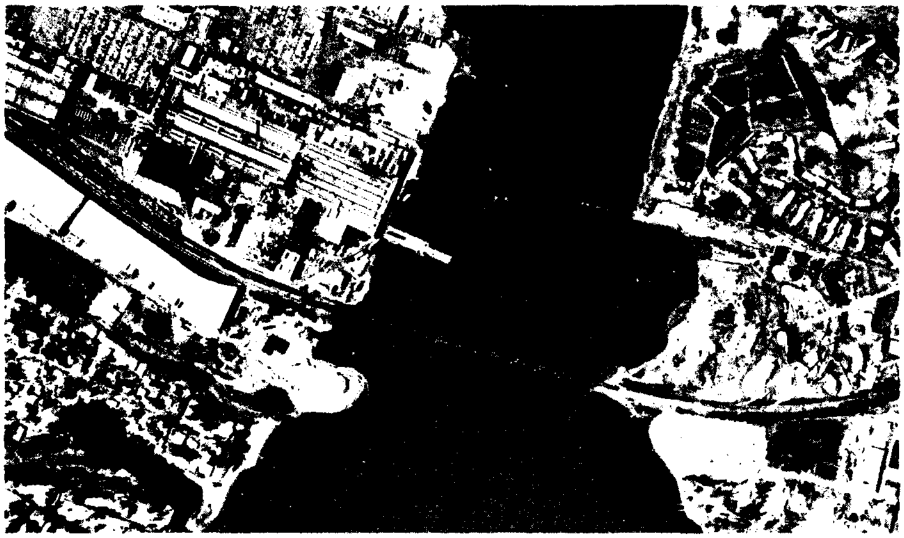
BH = HIGHWAY BRIDGE
Br = RAILROAD BRIDGE
R = RESIDENTIAL
T = STORAGE TANKS
W = WATER
J = JETTY
Dg = DAMP GROUND
rr = RAILROAD
b = BUILDINGS
pl = PIPE LINE

NORTH

WESTINGHOUSE Ka BAND SAR RADAR, 4 NOV 65, NASA

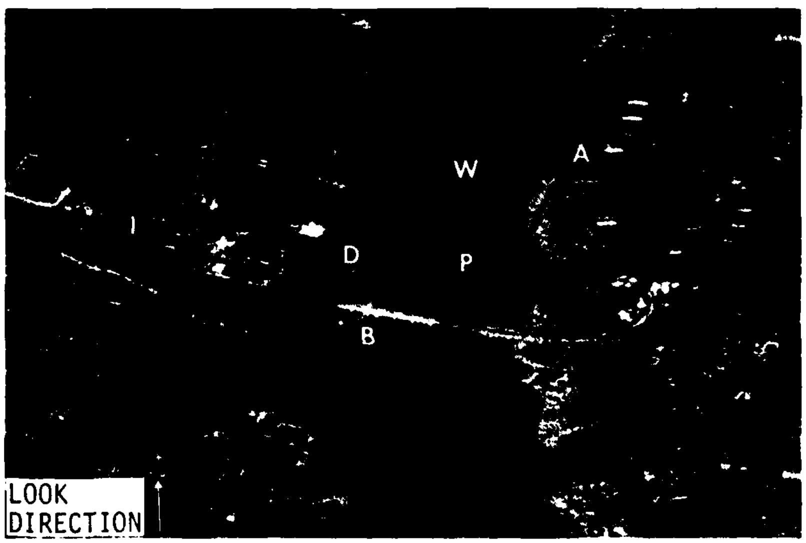
BENDIX THERMAL IR, FEB 78, ESCA-TEC'' CORP.

FIGURE A-1 -- CARLSBAD, CALIFORNIA



PANCHROMATIC, 4 FEB 76, SOUTHEASTERN VIRGINIA PLANNING DISTRICT

A--AGRICULTURE, B--BRIDGE (RAILROAD), D--DOCK,
I--INDUSTRIAL, P--PIER, W--WATER



X-BAND RADAR, 21 SEP 77, GOODYEAR AEROSPACE CORP.

FIGURE A-2 -- EASTERN BRANCH OF THE ELIZABETH RIVER, NORFOLK, VIRGINIA.

El Rio, California

An X-band radar image and a panchromatic photograph of El Rio, California, are shown in Figure A-3. El Rio lies just north of the city of Oxnard in Ventura County and 55 miles WNW of Los Angeles.

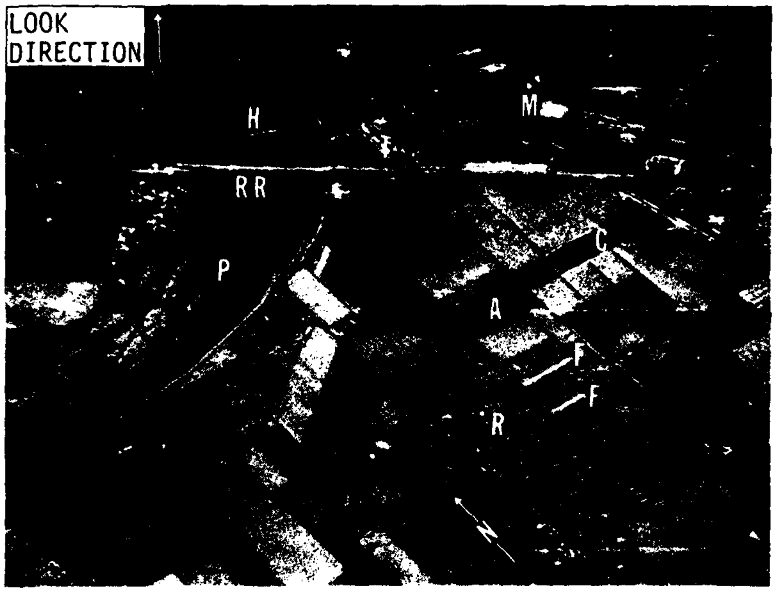
Major features in these scenes include the Santa Clara River which flows through the NW portion of the images, and the Southern Pacific Railroad and Highway 101, which both cross the river. The area includes commercial and residential buildings, along with orchards and other agricultural land. Since 1971, when the radar image was generated, there has been a decrease in agricultural areas largely due to the construction of roads and a complex of apartment buildings south of the Santa Clara cemetery, C.

The fields north of the cemetery and in the northern corner of the images are orchards. In the panchromatic photograph, they differ from other agricultural areas, A, in that rows are easily detected, and in most sections, individual trees can be seen. The orchards appear as bright, speckled-looking areas on the radar image. In some cases, the alignment of the trees can be discerned. The overall brighter return occurs because the trees and the spaces between them cause the radar system to "see" the orchards as areas of surface roughness when compared to fields with low-growing, closer-spaced crops, and those fields lying fallow.

Residential areas, R, can be recognized easily on both images. In the photograph, roads and individual buildings are found along with lawns, trees, and some swimming pools. Although such detail isn't present in this radar image, residential areas have a distinct signature consisting of dark-imaging roads which cut through the relatively brighter, coarse-textured areas of buildings.

Two fences, F, near the edge of one residential area are clearly apparent as bright bands on the radar image. These metallic structures are not as evident in the panchromatic photograph. Because it is early afternoon and the sun is to the WSW, determination of the positions of the east-west aligned fences is made difficult by the very short shadows they cast. However, the somewhat more defined shadows along the west and east sides of the block seem to indicate fences there also which image as bright but narrow and discontinuous strips on the radar image. They are less well-defined than the fences to the north and south because they lie parallel to the look direction. This example illustrates the importance of the effects of illumination angle and look direction on feature detectability.

Other metallic features are seen at the building, M, and trailer park, T. On the radar image, it is again noted that the N-S aligned trailers in the southern corner of the park don't produce signatures as bright as those parked at an angle to the look direction. Besides the metal-topped building itself, M, cars in the parking lot around it also produce strong returns. The two pairs of bright lines along Oxnard Blvd. (which exits the highway and heads SSW) may be metal guardrails which are not apparent on the panchromatic photograph.



A--AGRICULTURE
F--FENCE
H--HIGHWAY BRIDGE
M--METAL STRUCTURE
P--FLOODPLAIN
R--RESIDENTIAL
RR--RAILROAD BRIDGE
T--TRAILER PARK
C--CEMETERY

SAR X-BAND RADAR, 1 APR 71, RADC/IRRE

PANCHROMATIC, 29 JUL 75, TELEDYNE GEOTRONICS

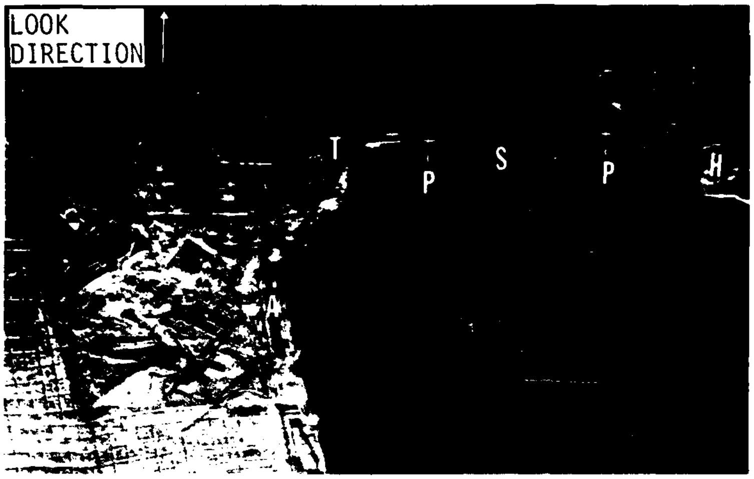
FIGURE A-3 -- EL RIO, VENTURA COUNTY, CALIFORNIA

Two bridges cross the floodplain, P, in the northern portion of the panchromatic photograph. The narrow railroad bridge, RR, images dark against the lighter colored background and its presence is enhanced by the shadow it casts, making it appear wider than it actually is. The divided highway bridge, H, is slightly darker than the floodplain it crosses, and the dark cross beams and shadows accentuate its presence. In the radar image, the railroad bridge is easier to spot than the highway bridge due to the fact that the rails are all metallic and produce a stronger return. The highway has metal supports, which are the brighter spots along the bridge, and guardrails, but the bridge itself is made of mostly non-metallic materials and is similar in tone to the floodplain below.

The floodplain, P, consists of light-colored sediments, and the river images light gray on the panchromatic photo. The darker areas represent vegetation. In the radar image, the sediments produce a weak return due to moisture content and the overall smoothness of the surface. Running water images an intermediate gray and vegetation has a relatively bright return.

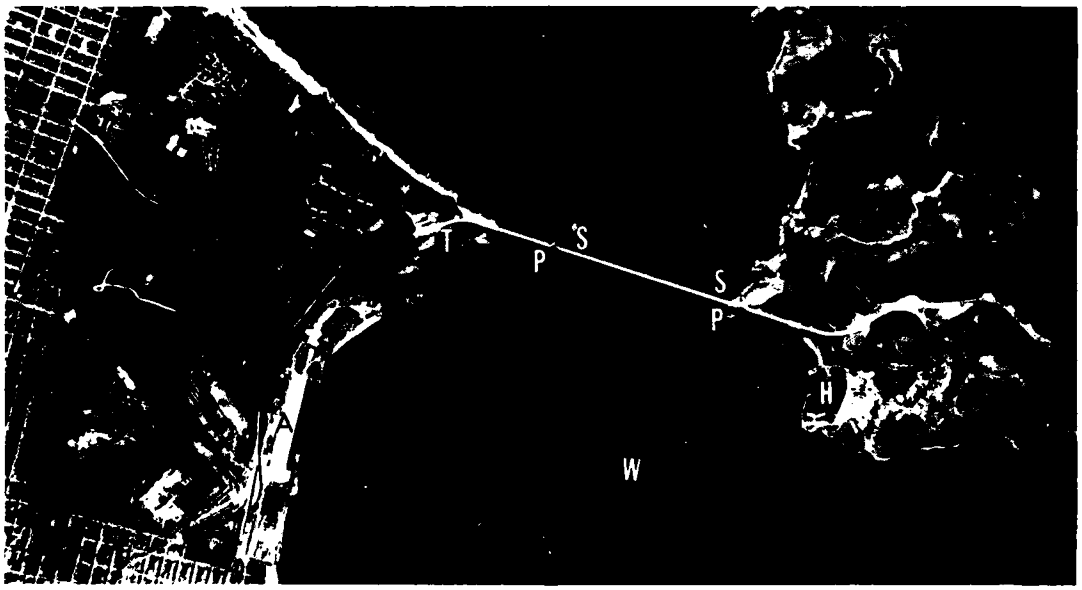
Golden Gate Bridge, San Francisco, California

The Golden Gate Bridge, which carries the major road link between Southern and Northern California, is presented in radar and panchromatic imagery Figure A-4). This vital transportation link and the adjacent military reservations (Presidio on the left and Ft. Baker Military Reservation on the right) can be seen in some detail on these two images. The bridge itself, when viewed vertically on the panchromatic picture, shows little detail of the pylon and cables. The shadow of the bridge can be utilized for picking out many of the details, such as the suspension structures and the angle of the cables. In considering the radar image of the bridge, it is possible to pick out the highly reflective road structure, the pylons, and the bridge superstructure. The steel construction provides many corner reflectors and large areas for detection. Beyond the bridge there appears to be a radar shadow which parallels the suspended roadbed and lies directly above it. An extra bright radar return is visible at the top of the north (right) suspension tower. The toll station adjacent to the (T) on the San Francisco (left) side of the bridge is also clearly visible on radar. It consists of a metal structure covering the entire roadway from side to side. On the panchromatic image the road coming across the bridge disappears into a tunnel at the far right side of the picture. Many of the quarters and maintenance buildings on the Presidio Military Base are highly reflective on the radar image. The water of San Francisco Bay contain some areas of radar return indicating rough water, probably resulting from high winds and tides that are generally present near the Golden Gate entrance.



A--AIRFIELD
H--HARBOR
P--PYLONS
S--SUSPENSION CABLES
T--TOLL HOUSE
W--WATER

SAR X-BAND RADAR, 7 APR 71, GOODYEAR AEROSPACE CORP.



PANCHROMATIC, 3 MAR 69, RADC/IRRE.

FIGURE A-4 -- GOLDEN GATE BRIDGE, SAN FRANCISCO, CALIFORNIA.

Houston, Texas

A radar image of the Houston, Texas, area accompanied by a portion of the Houston topographic map at the same scale, is shown in Figure A-5. The image was generated by the MARS SLAR system, which operates in the X band (3cm) HH polarized. Flight altitude was 4300 MSL flown at zero delay. Look direction is from south to north. Major landscape features include the Houston Ship Canal, which enters the image in the northeast and winds toward the downtown area. In the southeast corner is the William P. Hobby Airport. West of the downtown area, suburban communities are recognizable by the patterns formed by the streets and characteristic vegetation.

There are a number of features of particular interest for their radar signatures in this image. In the central city (A), a large black area with several spikes extending north, is seen. This is the radar shadow of skyscrapers in the heart of the city. Other parts of the central city exhibit a very bright return, which is caused by the square-sided buildings acting as corner reflectors. Southeast, at the downtown section, is an area of mixed industrial, commercial, and residential land uses, which produce a complex radar signature. Several very bright targets correspond to the locations of large metal warehouses and manufacturing facilities, while bright linear features are found to be commercial developments along major roads. The residential neighborhoods generally produce a less intense return, and appear as fairly even-toned gray areas resulting from the vegetation and street patterns. The Rice University stadium is visible in the lower center (B) and appears as a bright "doughnut"-shaped object, surrounded by the specular signature of the smooth parking lots. South of that is the Houston Astrodome which is under construction.

Powerlines are evident at several locations in the image (C, which is in the far range, shows the area enlarged for detailed description). In using strip flight patterns Motorola obtains at least 60% sidelap so the far range areas don't have to be used without the possibility for comparison in the near range. The 60% sidelap provides for three views of each area of interest. The signature for the powerline towers is unusually bright on the radar image, and is recognizable by the return and shadowing affect. The height of the tower structure can be computed when the delay and depression angle are known. The signature of each power pole is a bright dash oriented along the azimuth axis of the image. These powerline tower returns get larger with increase in range because of the clutter pattern. Each ground resolution element is saturated by the strong reflection, even though these structures are much smaller than the theoretical resolution element. Since the radar signature for each element is composed on an average for the reflectivity of the entire cell, the return from the power poles is sufficient to raise the average to the maximum, producing a white signature. Further, the azimuth axis of the signature for each structure is elongated because at least part of the pole is within the field of view for several successive scans. On each one, the signal is saturated by the reflection from that portion that is visible. Thus the azimuth dimension of each power pole is exaggerated several times. The exaggeration is greatest in the far range where azimuth resolution is at a maximum elongation.

FIGURE A-5 -- HOUSTON, TEXAS AND VICINITY. X BAND SLAR IMAGERY AND PORTION OF TOPOGRAPHIC MAP. IMAGE DATE 13 MAR 75, MOTOROLA AERIAL REMOTE SENSING, INC. SIDE LOOKING AIRBORNE RADAR IMAGERY. SCALE 1:250,000, FLIGHT ALTITUDE 4300'.

Houston, Texas (Detail)

An enlarged detail of this powerline area is shown in Figure A-6. Power poles are evident in the northern portion of this image (A). Note also the pseudo three-dimensional effect created by gallery forests and their shadows (C).

The striking radar signature of the power poles contrasts with their signature on panchromatic photography of the same area (Fig. A-7). Note that the primary indication that the poles are present on the photography comes from their shadow (several of which are indicated by black arrows), rather than the actual towers. Low sun angle photography would be advantageous for use in locating such features in the flat terrain.

Also included in the areas are several buried pipelines. At least one of these (A-A') was in place prior to 1965 (date of topographic mapping) but construction dates for the others are unknown. Although several pipelines can be detected and identified on the panchromatic photograph, none are evident on the radar image. Pipelines will not be detectable unless a slight depression or mount is left once the pipe is buried. Tailored radar flights specifically for this purpose greatly enhance the chance of detecting these anomalies. On such flights a low altitude and low depression angle would be used. The return signal would emphasize slight variation in the ground surface pattern. The pipelines are distinguished on the photograph because of the subtle linear disturbance of soil over the buried line. In the March 8 photograph, none of the fields contain crops and the pipeline route is evidenced by generally lighter soil tones. It is not known whether there is a chemical difference in surface soil composition due to mixing when the pipe was laid or if the tonal variation is caused by physical properties, such as moisture variation due to differences in grain size or compaction. Further evidence of the pipeline routes are seen where they pass through residential developments (A' and C'). The right-of-way is clear, and in some cases, residential streets are aligned along the path, which accentuates its presence.

Pumping installations (A) were identified at the intersection of two pipelines on the panchromatic photograph. These consist of small metallic pumps and associated equipment, and narrow dirt access roads. The pump stations do appear on radar as a small white spot, but are far too small to be resolved and identified by their function, but they can be detected. A series of these in a line would be a clue to their use.

Another feature of interest common to these two images is a railroad facility used for loading agricultural products. Two sets of buildings are evident at the end of numerous rail sidings (B) on the panchromatic photo. These appear to be built of metal, such as aluminum and produce a very strong radar return. The white radar signature includes all of the buildings and the area where rail cars could have been at the time of the overflight. Specific radar flight patterns can be tailored to detect railroads and railroad facilities. These flights may result in imagery which provides information on number of rail sets, switches, roadbed material, stations, repair facilities, railroad bridges, and trains.

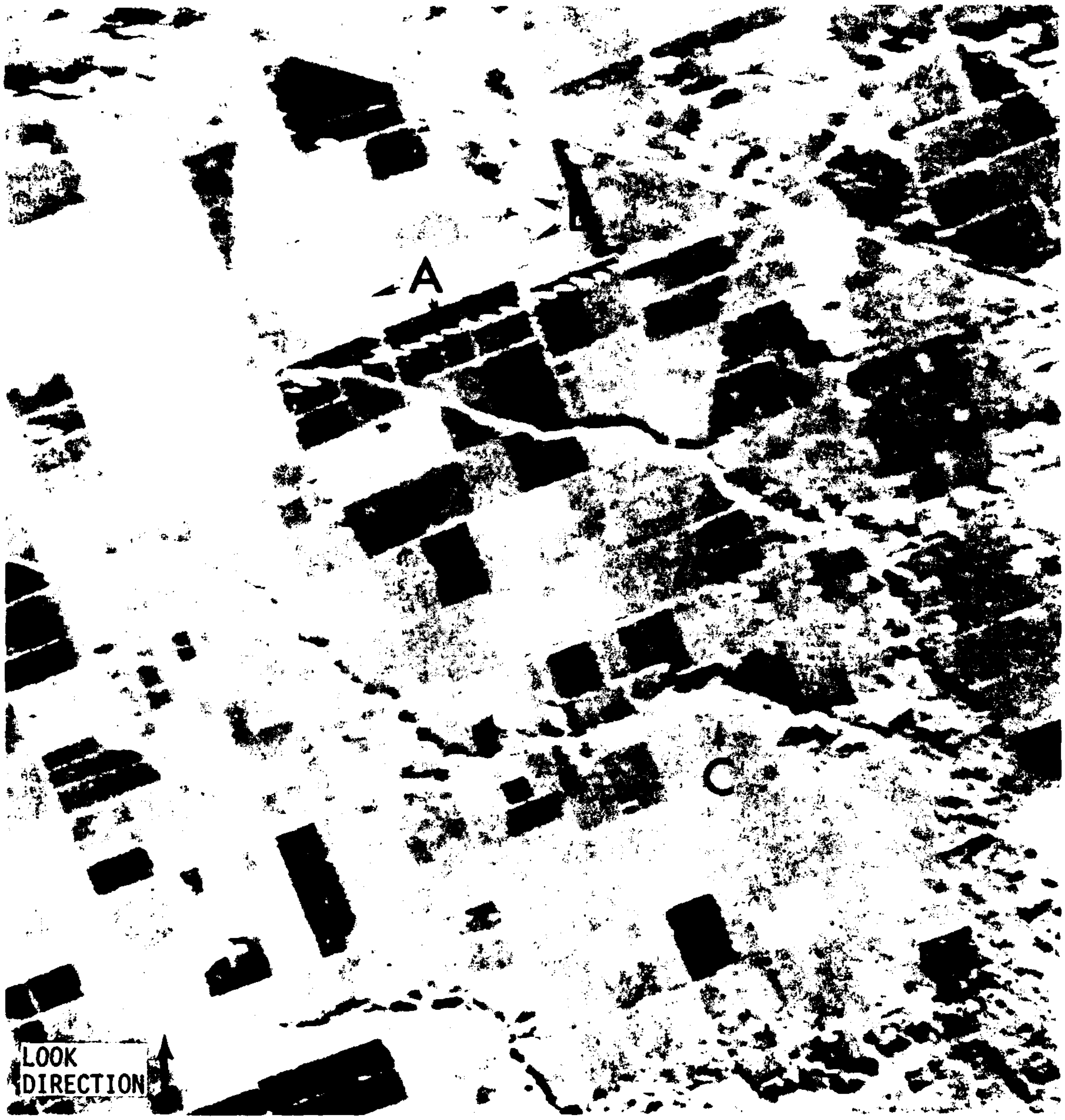


FIGURE A-6 -- ENLARGED PORTION OF FIGURE A-7. AREA NORTHWEST OF HOUSTON, TEXAS. SLAR IMAGERY TAKEN 13 MAR 75 BY MOTOROLA AERIAL REMOTE SENSING, INC. SIDE LOOKING AIRBORNE RADAR IMAGERY. FLIGHT ALTITUDE 4300'.

FIGURE A-7 -- AREA NORTHWEST OF HOUSTON, TEXAS. PANCHROMATIC PHOTOGRAPH TAKEN 8 MAR 79 BY WILSON/BALDWIN AERIAL SURVEYS, SCALE APPROXIMATELY 1:31,000

Los Angeles L-Band Radar Mosaic*

The importance of look direction on the radar signature of urban areas is shown by the L-Band mosaic of the Los Angeles Basin (Figure A-8). Orientation of the primary street pattern is a dominant factor affecting the strength of the radar return. In communities where streets run either perpendicular (north/south) or parallel (east/west) to the look direction, structures tend to act as corner reflectors, which produce a strong return and bright radar signature. Where street patterns are oblique to the radar beam, reflections are primarily away from the antenna and the signature is darker. A close examination of the radar mosaic reveals that the blocky signature pattern is a result of street orientation. Adjacent residential neighborhoods exhibit strikingly different tonal characteristics where there is an abrupt change in the survey pattern, as shown at 'X' on Figure A-8, despite the fact that land use patterns and building materials are identical for the two areas (local examples of this phenomena are discussed by Bryan 1979.).

The quantitative effects of survey orientation may be determined by comparing the angle formed by the street orientation and look direction to the mean intensity of radar signature for various communities. The effects of survey orientation on radar return may be observed where the angle is quite small.

The relationship between target orientation and radar signature has been evaluated by regression using spot density measurements taken from various locations in the mosaic. Sample locations were selected on the basis of tonal and textural homogenity and reference to surface street maps to determine the angle formed by streets and look direction. Multiple spot density measurements were made for each sample location. These data were run through a computer program which performed three types of two-dimensional regression (linear, geometric, exponential). Results are illustrated by Figure A-9.

Clearly, the radar return from areas where the survey is perpendicular to the look direction is much stronger than where an oblique angle is formed. The return decreases rapidly in intensity as this angle opens from 0° to 20°, and gradually flattens. A low point is reached at 45°, which indicates that at this angle, much more of the radar beam is reflected away from the receiving antenna. Curves plotted on Figure A-9 demonstrate best fits for each type of regression and it is not surprising that the exponential model produces the highest correlation coefficient.

The mechanism responsible for such a variety of community radar signatures relates to the strong tendency for individual buildings to be constructed with flat fronts parallel to the street. One may consider that buildings which are oriented away from the receiving antenna will not reflect a high percentage of the radar beam back to the receiver. At a small scale, such as the radar mosaic shown in Figure A-8 (1:350,000), the collective influence of several structures is incorporated into the community signature; however, the same phenomena applies to settings where structures are widely spaced. The ability to detect buildings on radar imagery on the basis of anomolous bright signatures depends a great deal on the buildings' orientation, irrespective of the setting.

FIGURE A-8 -- LOS ANGELES, CALIFORNIA AND VICINITY. SLAR (L BAND) BY JPL/NASA, SCALE 1:350,000.

Note: See Figure B-5 (p. 131) for SEASAT A image of this area.

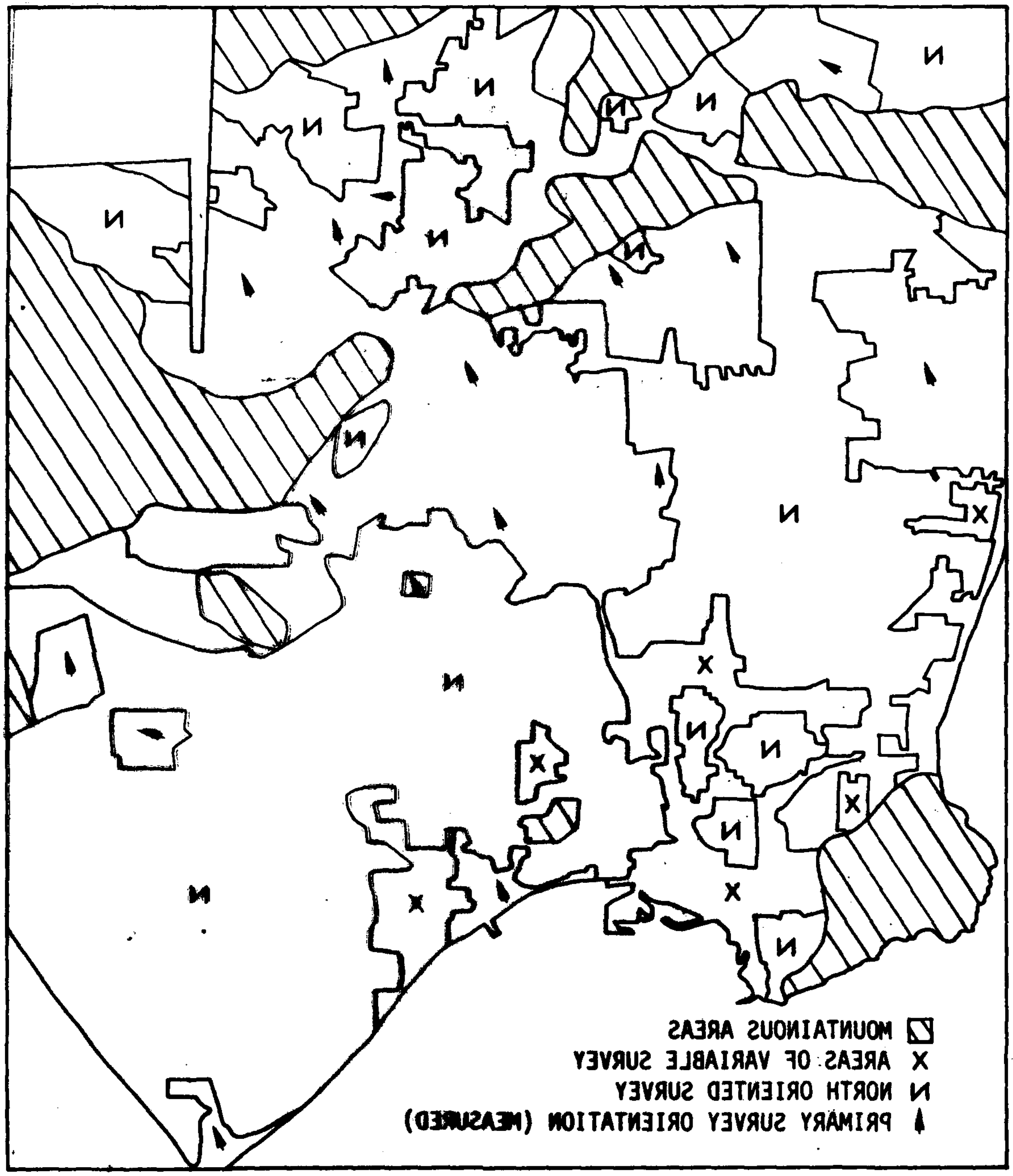


FIGURE A-8 -- OVERLAY TO LOS ANGELES L-BAND RADAR MOSAIC

PRIMARY LAND SURVEY DIRECTION/STREET ORIENTATION SHOWN BY ARROW OR "N". MOUNTAINS AND AREAS WITH VARIABLE STREET ORIENTATION SHOWN BY SYMBOLS LISTED.

Examples of small targets which produce anomolous radar signatures include metallic objects (fences, powerlines, power poles), buildings with tin roofs, railroad cars, and automobiles. The signature for each resolution cell on a radar image is composed of the average radar reflectivity of all objects in the cell. Even very small objects may cause the entire cell to have a bright signature if the reflectivity is high enough. In such cases, the entire cell appears white, even though only a small percent of the actual surface is covered by the reflective object.

* Note: L-Band is not the typical radar band used in military operations; however, it represents a possible future system.

Orientation may have an important effect on target resolution even when the target is below the theoretical resolution of a radar system. For example, consider a SLAR system with 20 meter range and 10 meter azimuth resolution. (Resolution in both dimensions is variable with depression angle). Two adjacent buildings are identical except for their orientation. One is perpendicular to the radar beam, while the other is 45° to the beam. Each presents a target area of 50 square meters within a resolution element of 200 square meters, and therefore each contributes 1/4 of the radar return. For this example, the surrounding surface is considered specular, and produces no return, so the total energy reflected from this resolution cell is produced by the buildings. According to the data derived from the measurements of the radar mosaic, one building will produce a return about 40% stronger than the other. With specular background, the perpendicular building will be resolvable, while the oblique building will not be bright enough to produce sufficient contrast. In either case, however, it is important to note that even though it may be detectable, the sizes of object cannot be measured below the resolution limit.

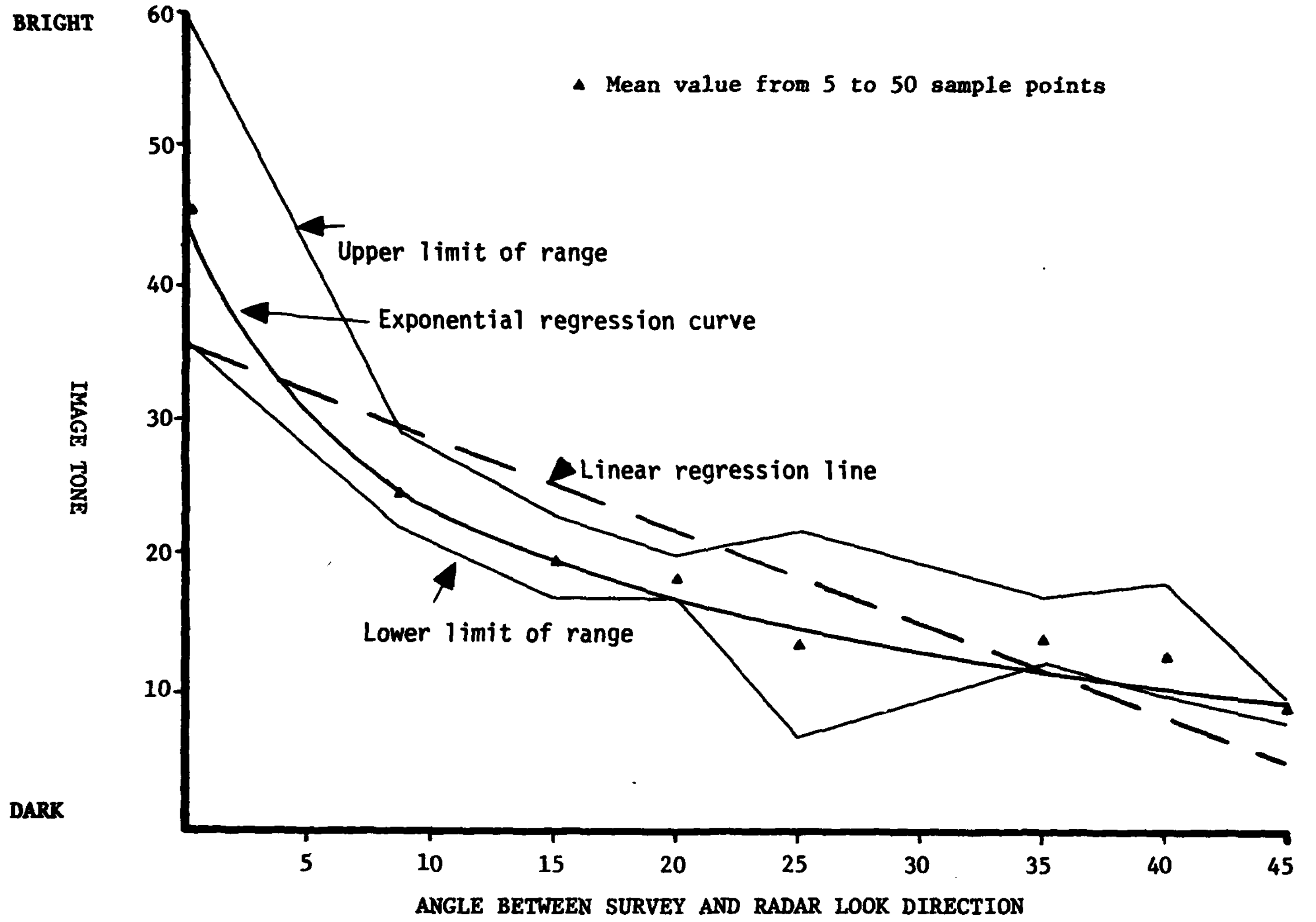


FIGURE A-9 - Regression of radar reflectivity vs. survey orientation for samples taken from L band imagery of the Los Angeles Basin.

Freight Yards, Middletown, Ohio

This TIR image of the Armco Steel Freight Yards in Middletown, Ohio, was taken on a cool March day with air temperature about 20°F (Figure A-10). The high radiant temperature from the three engines on the train (A), the tracks (B) and the building (C) are apparent. The engines are pulling the train, or are at least prepared to pull the train, since they are in full operation. Several of the train cars are warmer than the majority of the dark, low radiant temperature cars. These moderately warm cars were probably recently filled, possibly with a slightly warm liquid. The area around B, where there is a high radiant temperature, appears to be heated by an underground source of unknown origin. Much of the manufacturing area around the buildings at C is issuing a great amount of heat. The area is associated with the steel production and is probably heated from the foundries. The road beds for the tracks can be differentiated but the tracks themselves cannot be detected. A long linear structure at D, with the very low relative radiant temperature, is probably a covered conveyor belt or transport system covered by highly reflective material.

THERMAL INFRARED, HONEYWELL SCANNER, 1 MARCH 78, 1500' AMT, EPA, CITY OF MIDDLETON AND MEAD TECHNOLOGY LABS.

LEGEND

A = TRAINS
B = HOT SPOT
C = MAINTENANCE BUILDING
D = CONVEYOR FACILITY

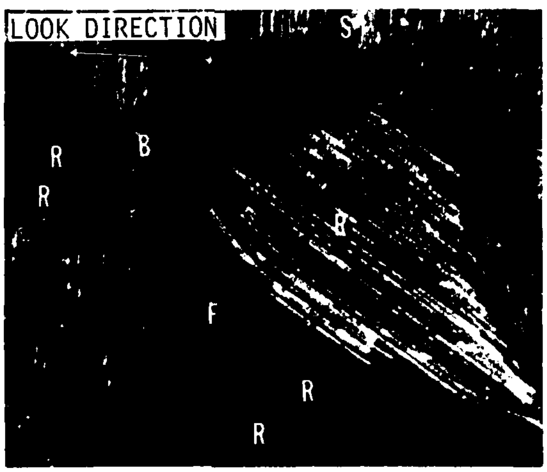
FIGURE A-10 -- MIDDLETOWN OHIO FREIGHT YARD.

Norfolk, Virginia, Naval Base

The panchromatic and radar images of the Norfolk, Virginia, Naval Base (Figure A-11) illustrates the patterns of a complex railroad yard and supply center. The high return from the railroad yard is caused by the numerous steel corner reflectors that are present on the rail cars and tracks. Since the panchromatic and the radar images were not collected simultaneously, it is impossible to confirm what cars are present. It does appear, however, that there are many more rail cars in the radar image than in the panchromatic image. The control building near the bridge does not show up on radar, while the panchromatic resolution is such that roof vents can be counted. The locations marked S contain what appears to be an electrical generating plant's stacks. The bright radar return is from the metal superstructure of the building. Rows of electric towers just to the right of the S are part of an electrical distribution system. The road which goes under the bridge at (B) contains a series of evenly spaced light standards which are clearly seen on the radar. In the lower part of the image, between where the two R's are located, a set of railroad tracks has been removed. This is shown by the bare ties, and no radar return from the metal tracks. The overall pattern of radar return from this type of site clearly indicates railroad operations.

PANCHROMATIC, 4 FEB 76, SOUTHERN VIRGINIA PLANNING DISTRICT

B--BRIDGE, F--NATURAL VEGETATION, I--INDUSTRIAL,
R--RAILROAD TRACKS, S--STACKS



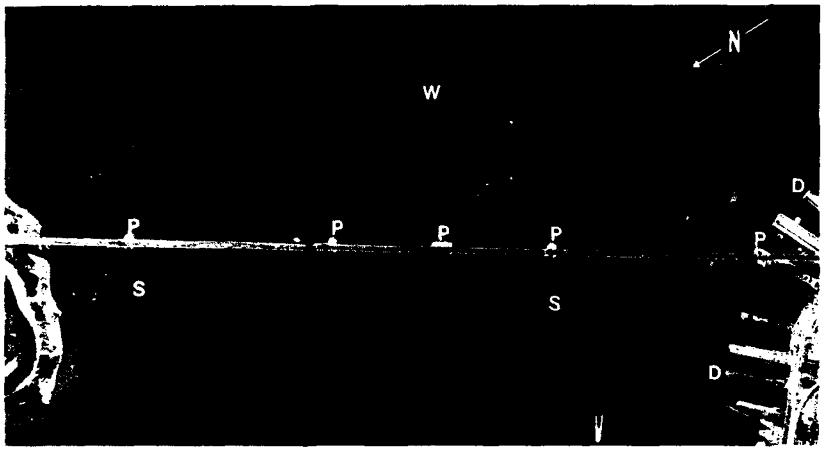
X-BAND RADAR, 21 SEP 77, GOODYEAR AEROSPACE CORP.

FIGURE A-11-- NORFOLK, VIRGINIA, NAVAL BASE

Oakland Bay Bridge, San Francisco, California

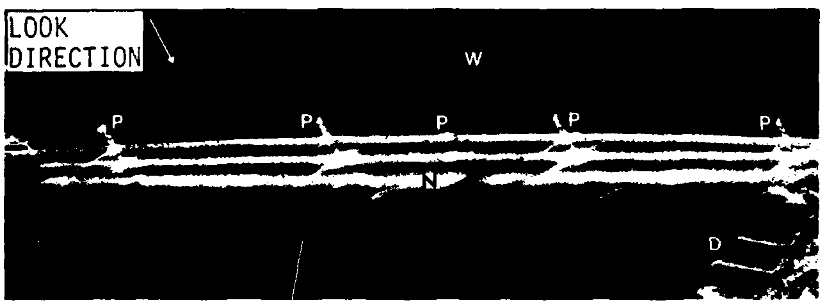
Figure A-12 consists of a panchromatic photograph and a radar image of the Oakland Bay Bridge, San Francisco, California. The bridge crosses northeastward from downtown San Francisco to Yerba Buena Island, which is on the left part of the images. On this double-decked structure, upper level traffic travels southwest and lower level traffic moves northeast. Under magnification, the individual cars' contours are seen and direction of traffic flow is confirmed. The bridge is supported by pylons, P, and suspension cables, and on the panchromatic photograph, the structure's configuration is clearly represented in the shadow it casts.

Piers, D, are evident in both images and the ship docked next to the bridge produces a strong radar return. Also having bright signatures are the pylons, cables, and the bridge itself. Because of the numerous corner reflectors inherent in the design of this bridge and the metallic materials used in its construction, the very strong radar return produces a noisy image as seen at N.



PANCHROMATIC, 21 MAR 77, AIR PHOTO CO., INC.

P--PYLON, S--SHADOW, D--DOCK OR PIER, W--WATER, N--RADAR NOISE



X-BAND RADAR, 11 MAR 71, GOODYEAR AEROSPACE CORP.

FIGURE A-12-- OAKLAND BAY BRIDGE, SAN FRANCISCO, CALIFORNIA

Phoenix, Arizona

Figure A-13 shows a panchromatic photograph of Sky Harbor International Airport in Phoenix, Arizona. Above it is an X-band SAR image of the same area. This image is parallel polarized (HH) and look direction is to the SSW as indicated by the arrow. In the eastern portion, several evenly spaced, bright strips appear. These are not associated with terrain features, rather they are electronic noise. Features in the airport area include the Salt River flowing from the east to the southwest in these images, and Interstate 10 (FW) in the southwest quarter.

The radar image indicates that with the exception of parking areas and buildings, most of the airport area consists of smooth terrain with some light vegetation. This area is generally dark or specular with slightly to moderately mixed signatures between runway strips, R, is produced by return from vegetation of various shapes and orientations. On the panchromatic photo, runways appear darker (reflecting less incident energy) than surrounding mottled gray vegetated areas.

Residential and commercial areas along the perimeters of both images are easily recognized. The rectilinear nature of the roads is well-expressed for both, and in the panchromatic photo, individual buildings can be resolved. The overall surface roughness and the ability of buildings to act as corner reflectors cause the bright appearance of the houses against the specular signature of the streets on the radar image. Other features with bright images are metallic objects, including airplanes, A; hangars, H; and cars in the parking lot north of the terminals, T.

It is noted that the objects' signatures seem to be oriented along an azimuthal axis. This effect occurs as the ground resolution cell is saturated by the strong return from the metal, and because there is at least part of the object within the field of view for several successive scans. This causes the object to appear larger than it actually is.

On the panchromatic photo, the Salt River appears as a slightly darker gray tone against the floodplain deposits. The alluvium in the eastern portion has a higher albedo than the poorly sorted gravel in the western portion. On the radar image, the rougher gravel appears brighter than the smoother surfaced alluvium. Other similar tones in the floodplain are caused by vegetation. There exist a few places where there are very strong returns in the eastern portion of the floodplain area. This is due to the structure of the terraces which act as corner reflectors.

RADAR, SAR, X BAND, 17 JAN 72,
GOODYEAR RECONNAISSANCE RADAR

R--RUNWAYS, A--AIRCRAFT, H--HANGARS, T--TERMINAL, FW--FREEWAY

PANCHROMATIC, RADC/IRRE

FIGURE A-13 -- PHOENIX, ARIZONA. SKY HARBOR INTERNATIONAL AIRPORT

Port of Long Beach

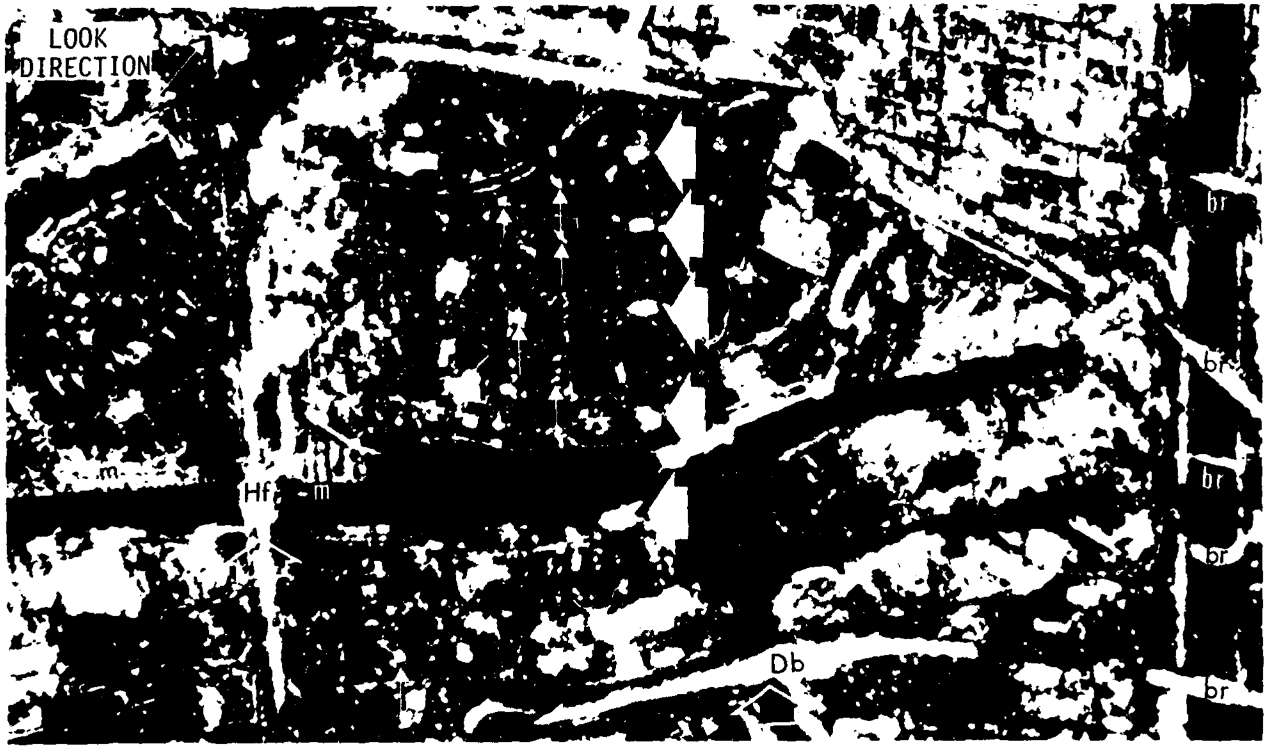
The Port of Long Beach, shown in Figures A-14, A-15, and A-16, is the location of Long Beach Naval Base, Terminal Island Naval Air Station, numerous oil and gas wells, and a wide variety of industrial port facilities. The panchromatic photograph of the area shows the wide variety of detail, including part of the urban area in the upper left corner. Many collection and distribution pipelines are present on the surface in the Wilmington oil field. It should be noted that the reflectance from metal and non-metal features are often similar, as opposed to the radar image (Figure A-15).

The first impression of the radar image is that it is somewhat confusing because of the large number of highly reflective targets. Close observation, however, supplies a great deal of information. The most striking feature is the Desmond Bridge at the lower part of the image. The superstructure of the bridge is all reinforced steel, which forms numerous corner reflectors. The powerline towers, which carry powerlines from a generating plant next to the bridge, also image as peak spots. The powerlines themselves cannot be seen. Many oil tanks, oil wells, metal buildings, freight yards, ships and boats are also obvious. In such an image, the great advantage of having an accompanying photo for target differentiation is obvious. The specular signal from the water is also advantageous in making feature identification.

The post-dawn thermal infrared image also shows the Desmond Bridge. The high reflectance from solar radiation masks many of the features. The cool signature from the shadow of the bridge structure is easily detected. This is also true of many of the tall buildings in downtown Long Beach. The Queen Mary is located in the lower center portion of this TIR image.

LEGEND: Db - DESMOND BRIDGE, Hf - HENRY FORD BRIDGE, rr - RAILROAD TRACKS, pl - PARKING LOT, m - MARINA, Dd - DOCKS. WO - WILMINGTON OIL FIELDS, NB - LONG BEACH NAVAL BASE, R - RESIDENTIAL, - OIL TANKS, - OIL WELLS, - BRIDGES, - POWERLINE TOWERS

FIGURE A-14 -- PORT OF LONG BEACH, PANCHROMATIC, 22 MAR 76, TELEDYNE GEOTRONICS.



LEGEND: Hf - Henry Ford Bridge, Db - Desmond Bridge, br - bridges,
powerline towers
oil wells

FIGURE A-15-- PORT OF LONG BEACH, RADAR (SAR), 25 FEB 77, GOODYEAR/JPL, SCALE 1:24,000.

LEGEND: Db - Desmond Bridge, rr - railroad, br - bridges,
Dd - docks, Dt - downtown area.

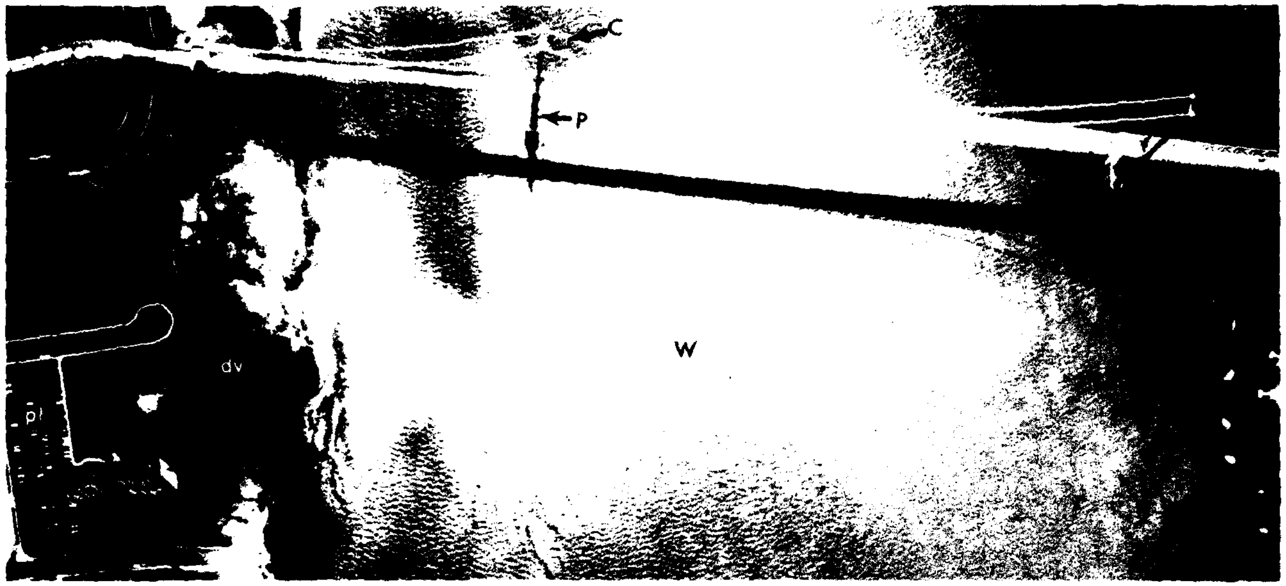
FIGURE A-16 -- PORT OF LONG BEACH, RS-14 THERMAL INFRARED,
26 JUN 70, NASA/HOUSTON, SCALE 1:24,000.

Poughkeepsie, New York

Figure A-17 is a panchromatic photograph of a portion of Poughkeepsie, southeastern New York. The major feature is the Route 44 Bridge, which crosses the Hudson River. On the west bank of the river, deciduous vegetation, dv, has a medium gray tone with darker shadows. The asphalt-paved parking lot, pl, and roads, r, have a lower reflectance than the bridge's concrete surface. Resolution is excellent; individual cars parked in the lot are clear, and one can almost count the windows in the high-rise building, H. Features associated with the bridge are side railings, support pylons, suspension cables, and the shadow which falls to the south. The high reflectance of the rough water and the similar tone of the bridge cause these two features to blend together at the center portion of the bridge.

Figure A-18 consists of the thermal infrared and radar imagery of the same bridge. On the thermal IR, the water is cooler than the land areas, indicating that this is a daytime image. The asphalt roads, r, and parking lot, pl, have a lower thermal inertia than the bridge material and therefore a warmer signature at this time of day. Although the sides of the high-rise, H, are warm, the roof is cool, which indicates it may be metallic. Support pylons, P, are cool on top and warmer at the base, suggesting metal set in concrete. The suspension cables, C, are metal and therefore have a cool signature, and are difficult to distinguish from the water below.

On the radar image, the bright signature of the high-rise confirms the suggestion that the cool signature of the roof on the thermal IR image is due to its metallic construction. Also producing strong returns are the bridge and its support pylons. The two bright strips along either side of the bridge are due to the metal railings and cables at these locations. The general N-S trend of the roads on the west bank can be seen, although electronic noise, N, obscures the area SW of the bridge. Individual roads, however, are difficult to differentiate from other flat lands of similar reflectance.

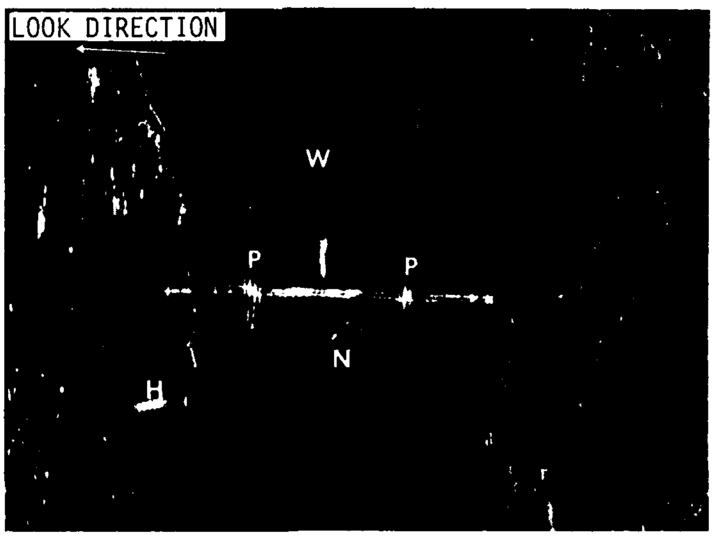


r--ROAD, pl--PARKING LOT, dv--DECIDUOUS VEGETATION, P--PYLONS, W--WATER, C--CABLES, H--HIGH-RISE BUILDING

FIGURE A-17 -- POUGHKEEPSIE, NEW YORK, PANCHROMATIC, 21 SEP 71, RADC/IRRE.

MAIRS THERMAL INFRARED IMAGE, 24 MAR 70, RADC/IRRE.

C--CABLES, H--HIGH-RISE BUILDING, pl--PARKING LOT, P--PYLON, r--ROAD
N--ELECTRONIC NOISE, W--WATER



AN/UPD-4 RADAR, 26 JUN 72, RADC/IRRE.

FIGURE A-18 -- POUGHKEEPSIE, NEW YORK.

Pt. Mugu, California

A panchromatic photo of the Pt. Mugu, California, area and a thermal infrared image of a portion of the area are shown in Figure A-19. Figure A-20 is an SAR X-Band radar image which covers the same general area. These three images span a four-year period and several changes have occurred. First, there has been an increase of marshland area in the northeast poriton of Mugu Lagoon due to deposition of sediment from Calleguas Creek, which enters the lagoon from the north. There is evidence of this ongoing deposition in the radar image where an area of scattering suggests marsh grass growth in the surroundind darker water. Two other changes have occurred in the lagoon area east of the major N-S trending road. They are the removals of a bridge across the lagoon and a pier on the north side of the bar.

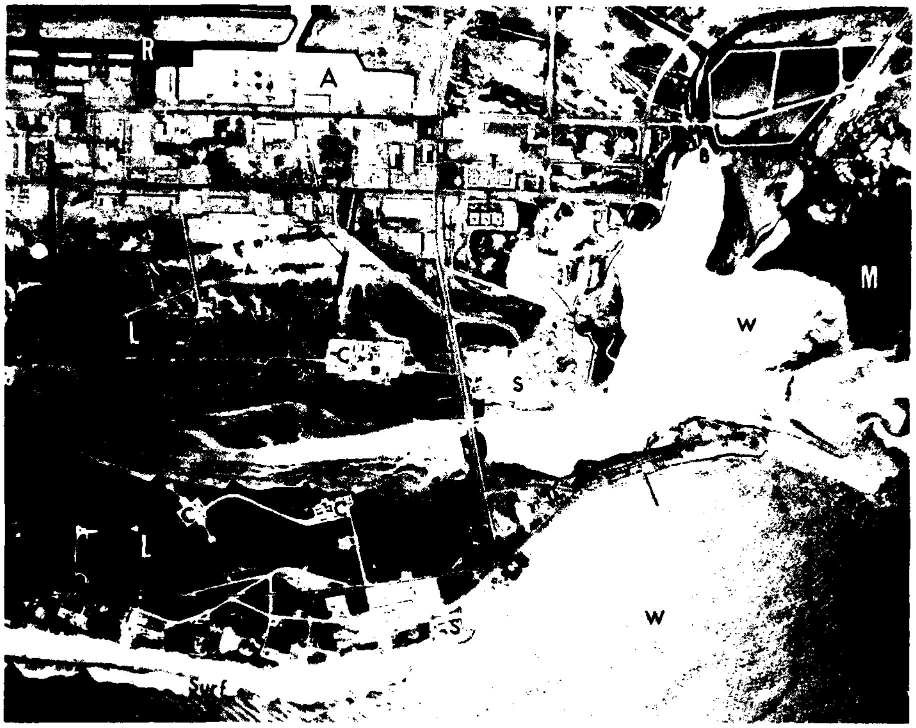
The high resolution of the panchromatic image makes it most useful in identifying objects and determining their functions. For example, the towers associated with range controlsites at the Pacific Missile Test Center are evident as bright spots casting comparatively long shadows. On the radar image these sites appear only as clusters of high reflectance. In the thermal IR, metallic objects with smooth surfaces, such as those at S, image cooler. On radar, metallic objects, including airplanes, A, and storage tanks, T, have strong returns and therefore bright signatures.

Other smooth, non-metallic surfaces such as runways, R, and roads are specular targets where incident energy is reflected almost totally with very little returning to the antenna of the radar system. These surfaces have a dark signature on the image. This specular reflectance also accounts for the dark appearance of calm water, W. Water also images darker than adjacent land areas in the TIR image. This occurs because convection currents, which tends to distribute heat evenly in water, do not occur in land areas.

The differences between wet and dry ground are well-defined in both images of Figure A-19. On the panchromatic photo, marshland, M, and other damp ground reflects less light and appears as the dark areas around the lagoon. Evaporation in areas of wet ground causes a cooling effect so on the TIR image, marshlands show up as the darker gray land areas. These lands are less well-defined in the radar image where they appear as areas of high reflectance. This bright signature is most likely due to the presence of vegetation, causing high return, and is similar to the signatures of other drier sections.

The major bridge across the lagoon is easily seen in both the panchromatic and radar images. It is less well defined in TIR as are all roads in general because the TIR image was taken with the gain set for detecting water features. The bridge to the east, however, is seen better in the TIR than the radar image. This is because of the difference in temperatures of water and the bridge material versus a similarity in specular reflectance between the two smooth surfaces.

Piers are easily detected in all three images. A very bright spot occurs at the end of one of the piers in the radar image. This is caused by the structure of a part of the pier acting as a corner reflector. For this imagery sample, it appears that the panchromatic image is best for determining identity and function, while the TIR and radar are valuable aids in revealing structure and material.



A--AIRPLANE
B--BRIDGE
C--RANGE
CONTROL
H--HANGAR
L--MISSLE
LAUNCH PAD
M--MARSHLAND
P--PIER
R--RUNWAY
S--METAL
STRUCTURE
T--STORAGE
TANKS
W--WATER

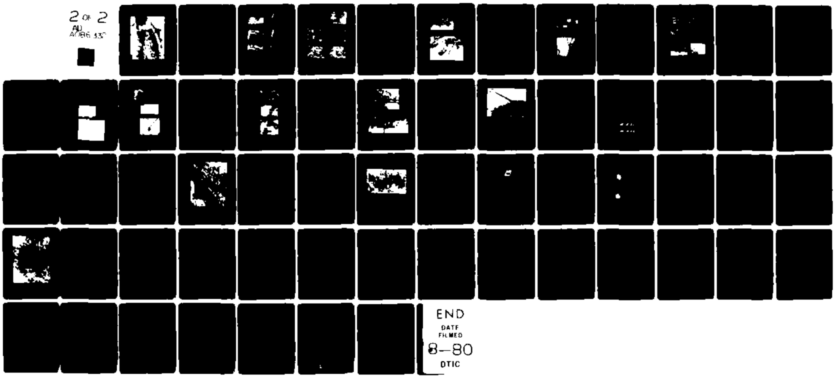
PANCHROMATIC, 29 JULY 1975, TELEDYNE GEOTRONICS.

BENDIX THERMAL INFRARED, APRIL 1972, ESCA-TECH CORP.

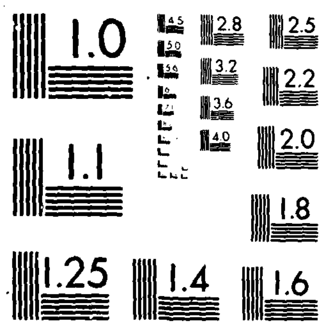
FIGURE A-19 - PACIFIC MISSILE TEST CENTER, PT. MUGU, CALIFORNIA

AD-A086 332 EARTH SCIENCE CONSULTING AND TECHNOLOGY CORP COSTA M--ETC F/6 8/6
MULTI-SOURCE IMAGE ANALYSIS.(U)
DEC 79 D D STELLER, M R MEL, D J SHIROMA DAAK70-78-C-0180
UNCLASSIFIED ETL-0208 NL

2 of 2
AD A086 332



END
DATE FILMED
8-80
DTIC



MICROCOPY RESOLUTION TEST CHART

FIGURE A-20 PACIFIC MISSLE TEST CENTER, PT. MUGU, CALIFORNIA, SAR X-BAND RADAR, 1 APRIL 1971, GOODYEAR AEROSPACE CORP.
A--AIRPLANE, B--BRIDGE, C--RANGE CONTROL, H--HANGAR, L--MISSLE LAUNCH PAD, M--MARSHLAND, P--PIER, R--RUNWAY, S--METAL STRUCTURE, T--STORAGE TANKS, W--WATER

Ripley, West Virginia

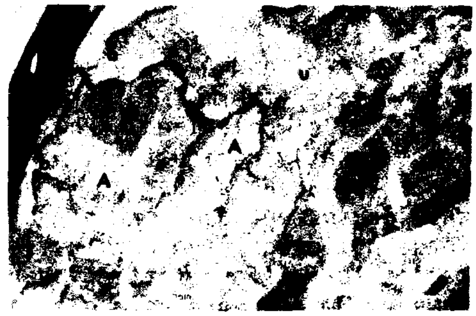
Figures A-21 and A-22, visible .48 - .53 micrometer (green), 9.0 to 11.4 micrometers (thermal infrared), and X- and L-Band radar imagery (both cross- and parallel-polarized) show the Ripley, West Virginia, area. The area is predominantly agricultural with surrounding forested areas. In both figures urban (u) areas appear as light tones in the .48 - .53 micrometer (green) wavelengths because concrete and roofing material used in the construction of these buildings have high reflectance in the green wavelengths. Contrast ratios for differentiating vegetation types (t = trees, A = agriculture) is, however, much poorer since greens are equally absorbed in these wavelengths. Water (w) is also hard to detect from the vegetated land because the lower region of the multi-spectral scanner's detection window is within the blue-green spectral region. Spectral reflectance from the water is partially absorbed, making differentiation between the two difficult. Since not much tonal contrast is present between the ground and the water, the bridge (b) is also not as apparent. The road (r) appears as one continuous feature.

In the thermal infrared imagery (9.0-11.4 micrometers) distinction between vegetation types are easier. Trees trap cool air under the branches. This air produces cooler signatures on the thermal infrared imagery which results in dark signatures. Urban areas appear as light-toned signatures because the roofing materials generally have high emittance materials. These materials absorb heat during the day and produce warm signatures on the thermal infrared imagery. Roads also appear as light-toned linear features for the same reason. Water in the thermal infrared image appears as darker tones because the TIR emittance of the water is lower than the surrounding ground during the day.

X-Band radar imagery is a short wavelength (2- 4 cm) radar system. For this reason most objects within Figures A-21 and A-22 have light tones because surface roughness values are very small. Only water, which acts as a specular target, is dark. Agricultural areas are medium to light toned because of the strong to moderate return of the radar signal from the low-lying crops. Trees are highlighted because of the abrupt change in height, which produces a radar shadow affect. Residential areas (u) in the X-Band parallel polarized image are bright because the corners of the buildings act as corner reflectors and produce very strong radar return. The residential areas are not as pronounced in the X-Band cross-polarized image because of the interference of the radar return. Roads in both of the X-Band images appear as dark linear features because of the smooth road surface which acts as a specular target.

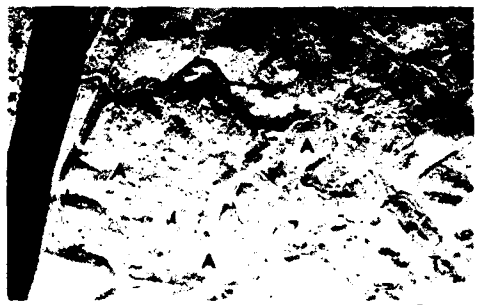
The L-Band radar system has a much longer wavelength (15-30 cm) and for this reason surface roughness values are also much larger. In the L-Band image, distinction between crops (dark tones) and forested areas (medium to light toned) are more readily distinguishable. Resolution in the L-Band parallel polarized mode is less than in the cross-polarized mode because as the radar signal strikes the ground, the vegetation tends to reflect the radar signal in all directions. When the signal returns to the antenna (still vibrating in various directions) the cross-polarized antenna screens out all the random vibrations except for those vibrating at 90° to the original signal. This process eliminates random radar return, and in the Ripley image, produces an image with more or less discreet boundaries (i.e., higher contrast ratios).

0.48 - 0.53 um MULTISPECTRAL SCANNER, 21 OCT 77, ERIM



9.0 - 11.4 um MULTISPECTRAL SCANNER, 21 OCT 77, ERIM

X-BAND RADAR PARALLEL POLARIZED, 21 OCT 77, ERIM



X-BAND RADAR CROSS POLARIZED, 21 OCT 77, ERIM

L-BAND RADAR PARALLEL POLARIZED, 21 OCT 77, ERIM

L-BAND RADAR HV CROSS POLARIZED, 21 OCT 77, ERIM

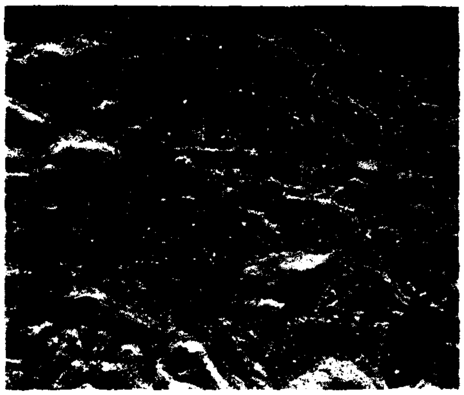
FIGURE A-21 - RIPLEY, W. VIRGINIA

LEGEND

b = BRIDGE
A = AGRICULTURAL
s = STREAM
T = TREES
w = WATER
r = ROAD
u = URBAN

0.48 - 0.53 um SENSOR (VISUAL),
21 OCT 77, ERIM

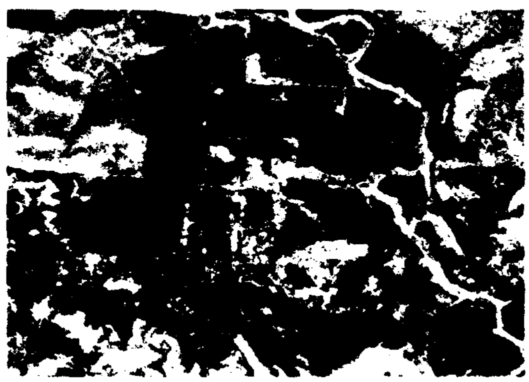
9.0 - 11.4 um SENSOR (TIR),
21 OCT 77, ERIM



X -BAND RADAR PARALLEL POLARIZED,
21 OCT 77, ERIM

X-BAND RADAR CROSS POLARIZED,
21 OCT 77, ERIM

L-BAND RADAR PARALLEL POLARIZED,
21 OCT 77, ERIM



L-BAND RADAR CROSS POLARIZED HV,
21 OCT 77, ERIM

LEGEND

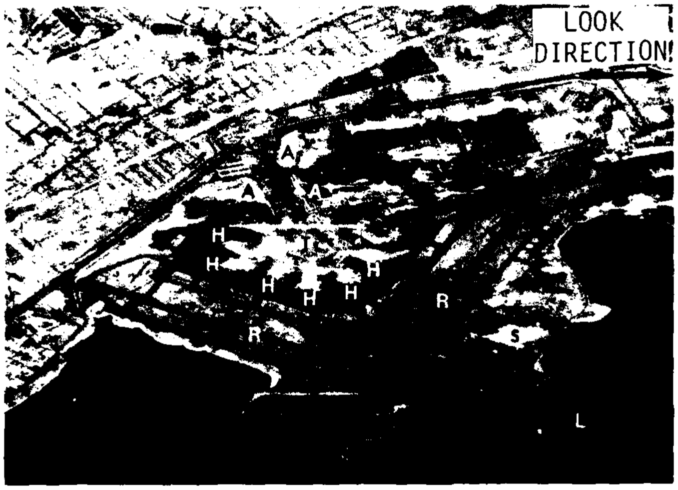
r = ROAD
c = WATERWAY
A = AGRICULTURAL
u = URBAN
T = TREES
W = WATER

FIGURE A-22- RIPLEY, W. VIRGINIA

San Francisco International Airport

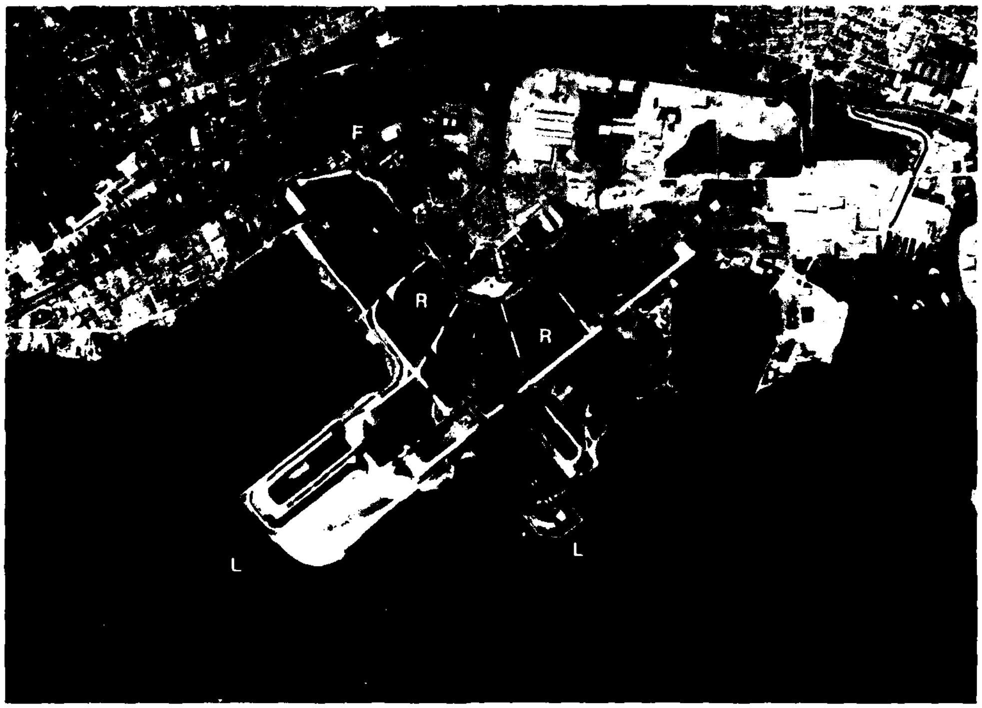
San Francisco International airport has many features readily identifiable in both the panchromatic and radar imagery (Figure A-23). On the radar image the runways, loading areas, freeways, and the water act as specular targets and give low radar return or dark signatures. Any metal structures such as buildings, radio towers, cars and airplanes give very strong radar returns and thus a very bright signature. The grass in between the runways gives a medium tone due to the various positions of the blades of grass. The grass acts as both (specular) smooth surface and a rough surface, thereby imaging a medium tone. The residential area in the upper right-hand corner of the image gives a medium to bright signature due to the angular orientation of the streets to the radar look direction. Also, the houses act as corner reflectors which produce strong radar returns. The approach lights (L) are small objects, but due to the high resolution of both the radar and panchromatic images, the thin lines of lights are recognizable.

In the panchromatic image, the same features can be identified. More detail around the loading area can be observed because the panchromatic image is dependent on reflected light rather than reflected radar beam. In the radar imagery, details of the loading area are masked because of the strong return given by the metal objects (planes and radio towers). In the panchromatic image the aircraft are highlighted by the fact that they have light colors (low albedos) and are on top of concrete slabs, which are darker in color. This high contrast ratio gives a higher resolution in these areas. Under magnification the cars can be identified for the same reason. The runways appear to have lighter tones because of low albedos compared to the grass, which has a medium to dark tone. The approach lights over the water are again enhanced because they are positioned over top water (dark) and have high contrast ratios.



A--AUTO PARKING
F--FREEWAY
H--AIRPORT HANGAR
L--APPROACH LIGHTS
R--RUNWAY
S--METAL BUILDINGS
T--MAIN TERMINAL

SAR X-BAND RADAR, 1 APR 71, GOODYEAR
AEROSPACE CORP.



PANCHROMATIC, 3 MAR 69, RADC/IRRE.

FIGURE A-23 -- SAN FRANCISCO INTERNATIONAL AIRPORT,
SAN FRANCISCO, CALIFORNIA.

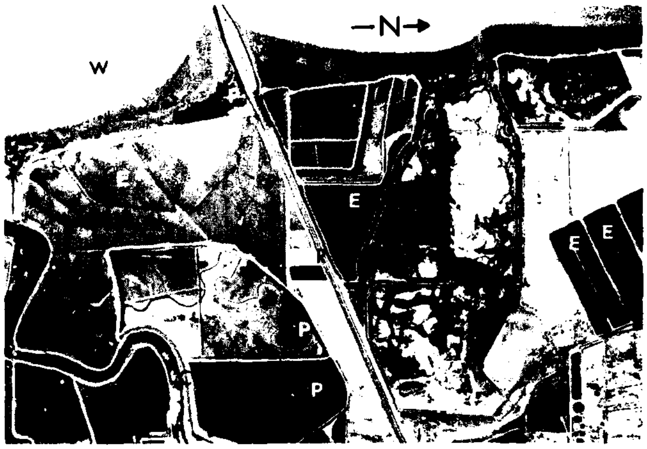
San Lorenzo, California

Figure A-24 is a panchromatic photograph accompanied by an X-band radar image of the Johnson's Landing Salt Evaporite Ponds. Johnson's Landing is near San Lorenzo, California, in the southern part of San Francisco Bay.

Because light penetrates water to some degree, it is difficult to tell whether or not the shallow ponds, E, held any water at the time the panchromatic photograph was obtained. However, the very dark signature of these areas on the radar image indicates that at the time this image was generated, there was at least some water in the ponds. The low radar return in the canal, C, suggests that water flows here also.

In the panchromatic photograph, powerline towers, P, appear as light-toned boxes with V-shaped shadows which fall to the east. On the radar image, these metallic structures produce strong returns and are expressed as bright dashes oriented in the range (look) direction.

The unflooded land north of the road, R, produces a mixed signature which is similar on the two images. The lower ground, along the numerous channels, has a higher moisture content and a darker tone than the drier areas. On the panchromatic photograph, the difference in tone is not representing a moisture difference as much as it is the high albedo of the salt deposits.



PANCHROMATIC, 6 JUN 77, AIR PHOTO CO., INC.

E--EVAPORITE PONDS, P--POWERLINE TOWERS, W--WATER, C--CANAL

X-BAND RADAR, 21 APR 71, GOODYEAR AEROSPACE CORP.

FIGURE A-24 -- SAN LORENZO, CALIFORNIA
JOHNSON'S LANDING SALT EVAPORITE PONDS

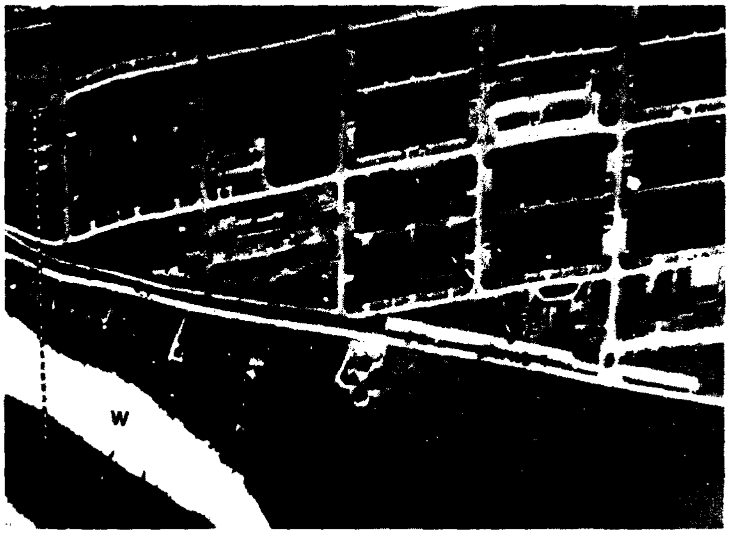
Scotia Naval Depot, New York

As previously mentioned, different objects produce different signatures with different sensors. In looking at the Scotia Naval Depot imagery (panchromatic, thermal infrared, and radar), Figure A-25, we see that differences in terrain features are expressed by tonal variations caused by different properties of the sensors and geometric relationships of the objects. An example of this is found by studying different vegetation types. There are two basic types of vegetation present in the Scotia, New York, images--trees and grass. By visual interpretation of the thermal infrared imagery, only subtle variations are observed. This occurs where warm air collects under the tree canopy and blooms out at the grass-tree boundary producing a light gray (warm) tone. However, because the trees are a darker color (lower albedo) than the grass in the panchromatic images, the difference in contrast facilitates the identification of the two types of vegetation. In looking at the radar imagery, again, only a subtle variation can be observed between vegetation types. The border areas are enhanced on the radar imagery but for reasons different than in the thermal infrared image. This density anomaly is produced by the trees acting as obstructions to the radar signal. This border is normal or perpendicular to the look direction of the radar antenna, which causes the radar signal to be strongly returned, producing a bright signature at boundary between the grass and trees.

Water present in the lower left side of the images gives a different signature according to the sensor used. In the thermal infrared image, the water is warmer than the surrounding features and produces a light tone. This indicates that this is a nighttime image, and convection is keeping the water surface temperature relatively warm. In the panchromatic image, the tone is dark due to the absorption properties of water to light. In the radar image, the signature is dark because the water acts as a specular target, reflecting the radar impulse away from the antenna.

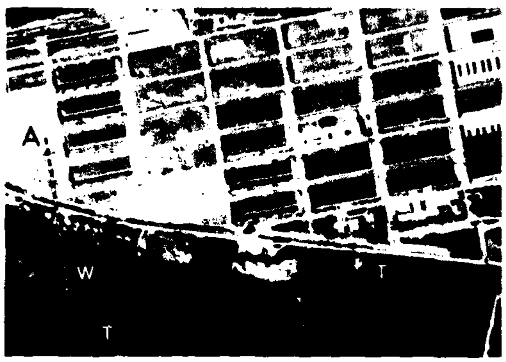
Roads in the thermal infrared image are light-toned due to warm temperatures encountered on the asphalt surfaces. In the panchromatic image, the roads are recognized by their linear arrangement around buildings and by their lighter tone. In the radar image these are only inferred to be present because they are actually washed out. This results for two reasons: (1) they act as specular targets and as such yield low returns, and (2) the larger buildings adjacent to the roads produce strong radar returns which obscure the roads. The roads are inferred from the image because the parallel alignment of buildings generally include access roads next to them.

Large and small dwellings (barracks, warehouses, single residences, etc.) are generally differentiated by size and by presence or non-presence of other related features (parking lots, other buildings, loading areas, etc.). The large structures in the upper region of each image are identified as barracks because of the presence of several walk-ways only on one side of the building and no presence of parking areas or loading docks. It is also known that the



B--BARRACKS
G--GRASS
R--ROAD
W--WATER
T--TREES

THERMAL INFRARED, 8-14μm BANDWIDTH,
10 SEP 72, MAIRS, RADC/IRRE-GOODYEAR.



PANCHROMATIC, 8 SEP 76
RADC/IRRE-GOODYEAR.

AN/UPD-4 RADAR SYSTEM
29 JUN 72, RADC/IRRE-
GOODYEAR.

FIGURE A-25-- SCOTIA NAVAL DEPOT, SCOTIA, NEW YORK.

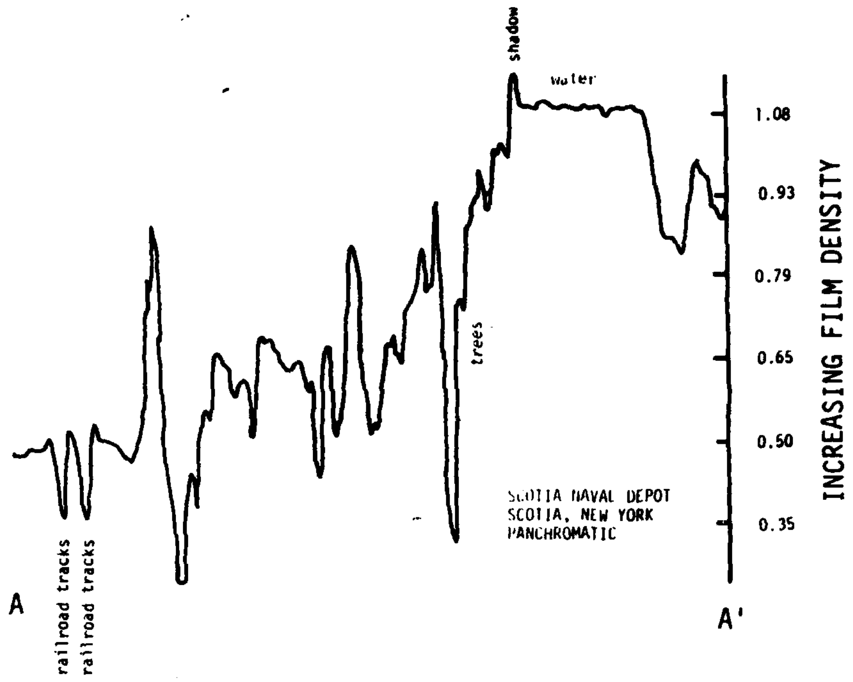
imagery is of a Navy base. On the thermal infrared image, the walk-ways and air vents are considerably warmer than the building itself due to differences in thermal properties and warmer air coming from inside. In the panchromatic imagery, the buildings appear to have fairly high relief (2 or 3 floors) because the building shadow is quite large (long). In the radar image, only one side of the buidling is observed. This results from the fact that the wall is facing at right or near right angles to the antenna and acting as a corner reflector, thus creating a strong return.

Density Profiles, Description

In analyzing panchromatic, thermal infrared and radar imagery of Scotia Naval Depot, the main characteristics evaluated are buildings, vegetation types, transportation types (roads, railroads, water) and large water bodies. On a detailed study using an isodensitometer, graphs are plotted by measuring the variation in signal responses of different objects, and are recorded as film densities. Line AA' and BB' are cross sections across the panchromatic and thermal infrared images of Scotia, New York.

In the panchromatic image, the signature of the water has the highest density of the entire image. Trees and grass produce lighter tones due to the reflectance properties of the leaves. Buildings made of concrete and the surrounding bare earth (soil) appear light-toned because of the high albedo of these materials. As observed on the density graphs, the densities become less as we move from A' to A (water to Depot Compound).

In the density graph of the thermal infrared image, Figure A-26, we notice only small variations in densities except where very warm materials are encountered. Analyzing the density graph from B' to B we see that the water is considerably warmer than the surrounding ground. This is indicated by the low density on the film density graphs. The trees and grass show very high densities (cool), but differentiation between the two is not possible. When the density slice cuts across roads (asphalt), low film densities (light tone) are recorded due to the higher temperatures of the materials. Fallow ground, grass and trees are all cool materials, thus producing high film densities (dark).



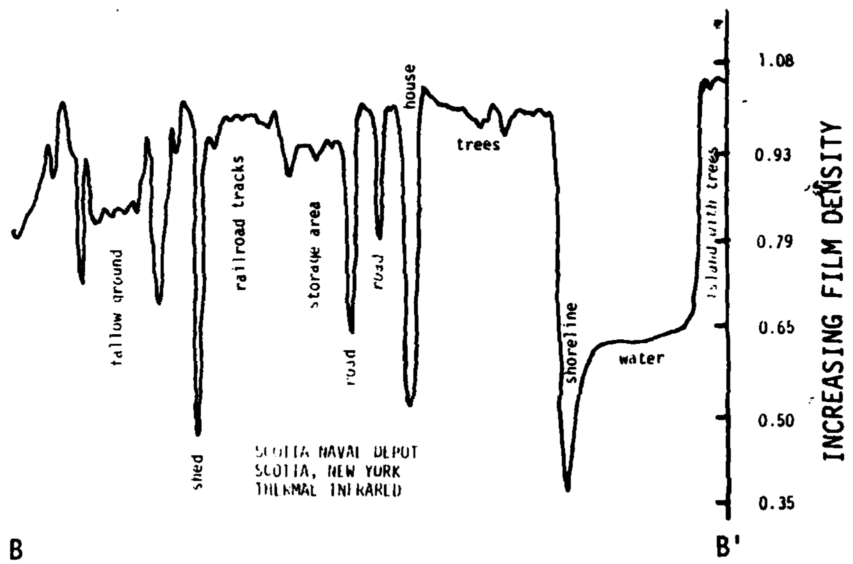


Figure A-26 - Scotia Naval Depot, Scotia, New York. Density graphs.

Stockbridge Test Site, Stockbridge, New York

The Stockbridge Missile Test Site is located in central New York State near Rome Air Force Base. Figure A-27 is a panchromatic, radar, and thermal infrared set of images of a launch pad area.

The missile launch area is surrounded by deciduous vegetation, dv, which appears as a darker, coarser-textured area on the panchromatic photo. On the radar image, dv has a mixed tone and casts shadows away from the look direction. On the nighttime thermal IR image, dv appears warmer than the dark roads and intermediate gray cleared areas because the vegetation insulates the ground and heat is retained under the branch structure and then released slowly after sunset.

Because metals make up the missiles and launch equipment, L, they appear as bright dots on the radar image, and are cooler (darker) on the TIR. Also having strong returns are the vehicles, V, which have a radar signature similar to the launch pads. They also have a cool signature on the TIR image. The smaller launch pads, L_2 in the upper right-hand corner of the TIR image, do not have as distinct a signature as their counterparts below. This also corresponds to the somewhat weaker radar return of these launch pads.

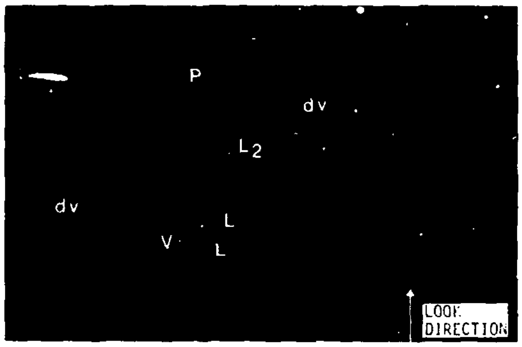
Powerline towers dot the upper left section of the radar image. Their path is clear because of the strong returns caused by these metallic corner reflectors. The area containing these towers is not covered on the other two images.

There is a dark feature seen in the panchromatic photo which is not on the other images. It is the shadow of the aircraft which photographed this area.

Figure A-28 shows three images of another Stockbridge test area. Vegetation and roads have signatures similar to those of Figure A-27. In the panchromatic photo, main features include an airplane, p, and a radio tower, r. Also evident are two missiles, m, which have very bright signatures due to the high albedos of the metal casings. A powerline runs from the radio station and support towers appear as small bright dots and are designated 'e'. These towers are clearly represented on the radar image as a series of bright dots, but are not evident on the TIR image.

Metal structures such as the airplane and buildings, s, have cool signatures on TIR. These objects produce strong radar returns and therefore bright signatures on the radar image. The radio station, r, has a cool signature and does not appear to be of the same material as 'p' and 's', yet it produces a strong radar return. This strong return is, in the most part, due to the corner reflectance properties of the building and its towers.

PANCHROMATIC, 15 JUNE 78, RADC/IRRE



LEGEND

V = VEHICLES
L = LAUNCH PAD
s = SURVEY AIRCRAFT SHADOW
dv = DECIDUOUS VEGETATION
P = POWER LINE TOWERS
L_2 = SMALL ROCKET LAUNCH PAD

AN/UPD -4 RADAR, 17 JUNE 77, GOODYEAR, RADC/IRRE

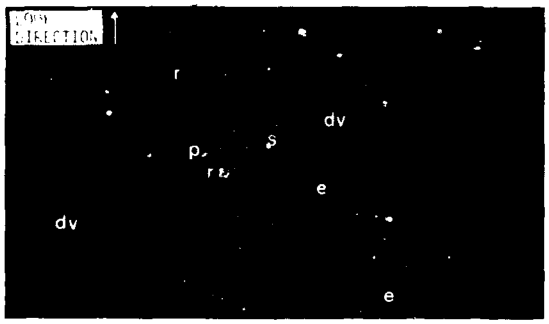
MAIRS THERMAL IR, 10 NOV 74, RADC/IRRE

FIGURE A-27 - STOCKBRIDGE TEST SITE, STOCKBRIDGE, NEW YORK

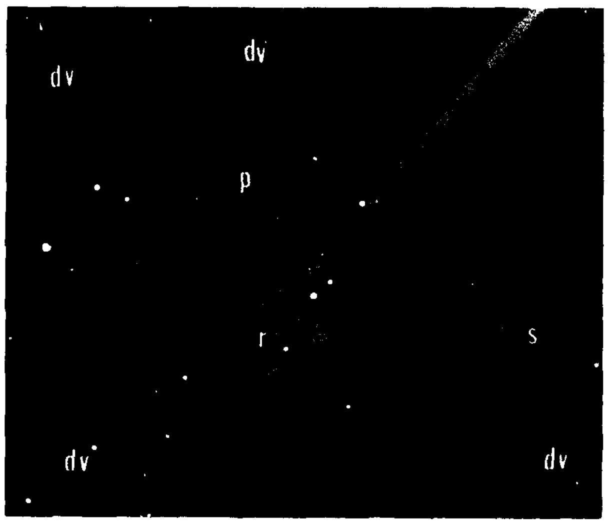
PANCHROMATIC, 15 JUNE 78, RADC/IRRE

LEGEND

r = RADIO TOWER
v = VEHICLES
p = AIRPLANES
m = MISSILES
e = POWER LINE TOWERS
s = STEEL BUILDING



AN/UPD-4 RADAR, 17 JUNE 77, GOODYEAR, RADC/IRRE



MAIRS THERMAL IR, 10 NOV 74, RADC/IRRE

FIGURE A-28 -- STOCKBRIDGE TEST SITE, STOCKBRIDGE, NEW YORK

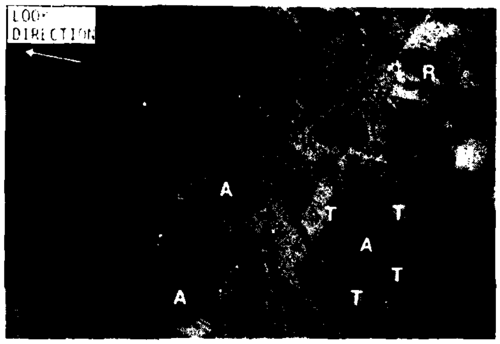
Sussex County, Delaware, Cape Henlopen

Panchromatic, radar, and thermal infrared images of a portion of Cape Henlopen, Delaware, are shown in Figure A-29. This area is chiefly agricultural and is located near the entrance of Delaware Bay into the Atlantic Ocean.

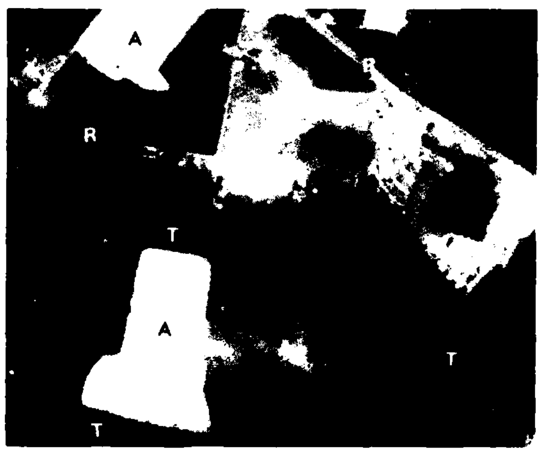
On the panchromatic photograph, agricultural fields, A, have a smoother texture and higher reflectance (albedo) than the darker-toned forested areas, T. Resolution is high; the individual units in the mobile home park, M, can be seen. Also clear are the median islands along the center of the divided road, R. This median strip shows also on the TIR image as a cooler band between two warmer strips. This coolness, plus the darker tone on the panchromatic photo, indicate these islands are covered with some type of vegetation.

In the radar image, areas with crops have a tone similar to that of the forests; however, the taller trees cast more definite shadows. The dark section in the lower right-hand quarter is agricultural land which has been cleared of vegetation. In the TIR image this cleared land has a warm signature. Areas with crops produce an intermediate gray tone and forests have a very cool signature. The individual units in the mobile home park have cool signatures due to their metallic structure, but the roads themselves are warm. On the radar image, the park has a bright signature; again, because of the metal structures. Roads are not apparent here because the strong return from the homes saturates the resolution cell and obscures the specular signature of the roads.

PANCHROMATIC, 15 MAY 77, USAETL



SLAR IMAGE, USAETL, RADAR TYPE AND DATE UNKNOWN



NASA JSC-247 THERMAL INFRARED, AUG 73, USAETL

A--AGRICULTURE, M--MOBILE HOMES, T--FOREST, R--ROAD

FIGURE A-29 -- CAPE HENLOPEN, SUSSEX COUNTY, DELAWARE.

San Onofre Nuclear Power Plant

The San Onofre nuclear power plant is located 2 miles south of San Clemente, California, and 1 mile north of the Camp Pendleton Marine Corps Base.

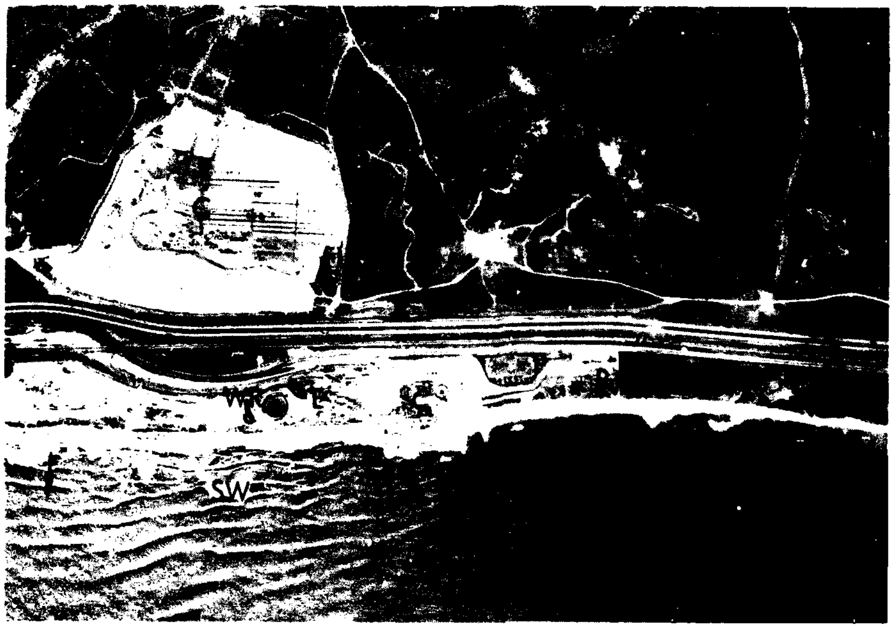
Ocean surf labeled "SW" is definable on both the radar and panchromatic images. On the panchromatic image the breakers (indicated by arrows) reveal the wind is blowing from the northeast or onshore direction. The thermal IR image shows a cool signature for the open water (Wo) relative to the shoreline. The scan lines on the TIR image are parallel to the ocean surf. Care must be taken not to mistake scan lines for ocean surf. The ocean surf (SW) on the radar image is detectable, as the wave train travels toward the beach. The radar signal is scattered due to roughness of the waves, the breaking surf shows up as white lines.

The San Diego freeway is visible on both the panchromatic and radar image. With magnification of 10X both cars and trucks can be counted and the 8 lanes on the freeway are distinguishable. On the radar image the freeway shows up as two black lines, the smoothness of the road causes very little scattering, therefore a poor radar reflection.

The railroad labeled "rr" is illustrated as a bright white linear feature across the center of the image. On the panchromatic image the railroad is less observable because of all the roads and highways which obscure the identification of the railroad tracks.

New construction of the nuclear power plant is labeled "C" on the three images, but the actual construction is only identifiable on the panchromatic image. In the thermal IR image buildings are evident but the stage of construction is not possible to determine. On the radar image buildings having high reflections due to rough surfaces are imaging bright white.

Powerlines are indicated on the panchromatic and radar images by arrows. The radar image displays distinct white dashes; on the panchromatic image the powerlines are less defined.



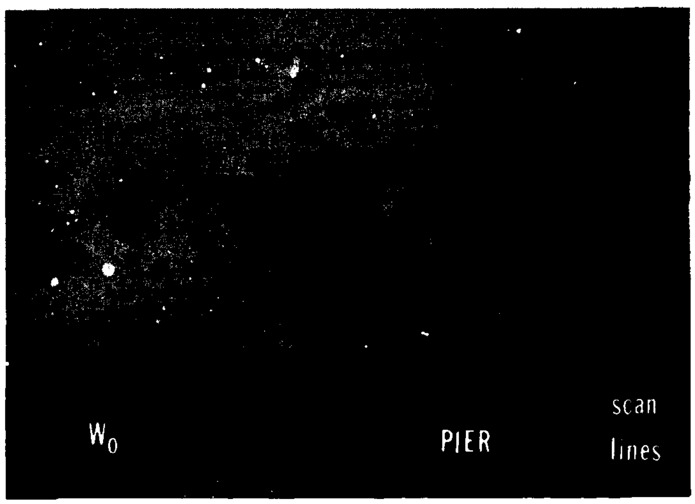
LEGEND

E-- NUCLEAR POWERPLANT
WR--RESERVOIR
P--PARKING
C--CONTRUCTION
W_O--OPEN WATER
SW--OCEAN SURF
W_S--STREAM
--POWERLINES
rr--RAILROAD

N

PANCHROMATIC, 15 JUL 75, TELEDYNE GEOTRONICS.

SAR X-BAND RADAR, 10 FEB 72
GOODYEAR AEROSPACE CORP.



BENDIX THERMAL IR, 1977, ESCA-TECH CORP.

FIGURE A-30 -- SAN ONOFRE NUCLEAR POWERPLANT, SAN ONOFRE, CALIFORNIA

APPENDIX B

RADAR IMAGERY

Radar imagery has become increasingly important for terrain analysis because of the versatility of radar imaging systems, which offer all-weather day or night operation. These sensors are described as "active" because they provide the source of illumination for a scene, as opposed to "passive" sensors, such as thermal infrared or photographic systems which image reflected or emitted radiation. Radar sensors transmit energy at microwave frequencies and produce an image of the terrain on the basis of the reflection of the transmitted energy from surface objects. Figure B-1 of San Francisco gives an idea of the detail detectable using a radar sensor. Basic factors which determine the radar signature of these objects include surface roughness, geometry, and complex dielectric properties.

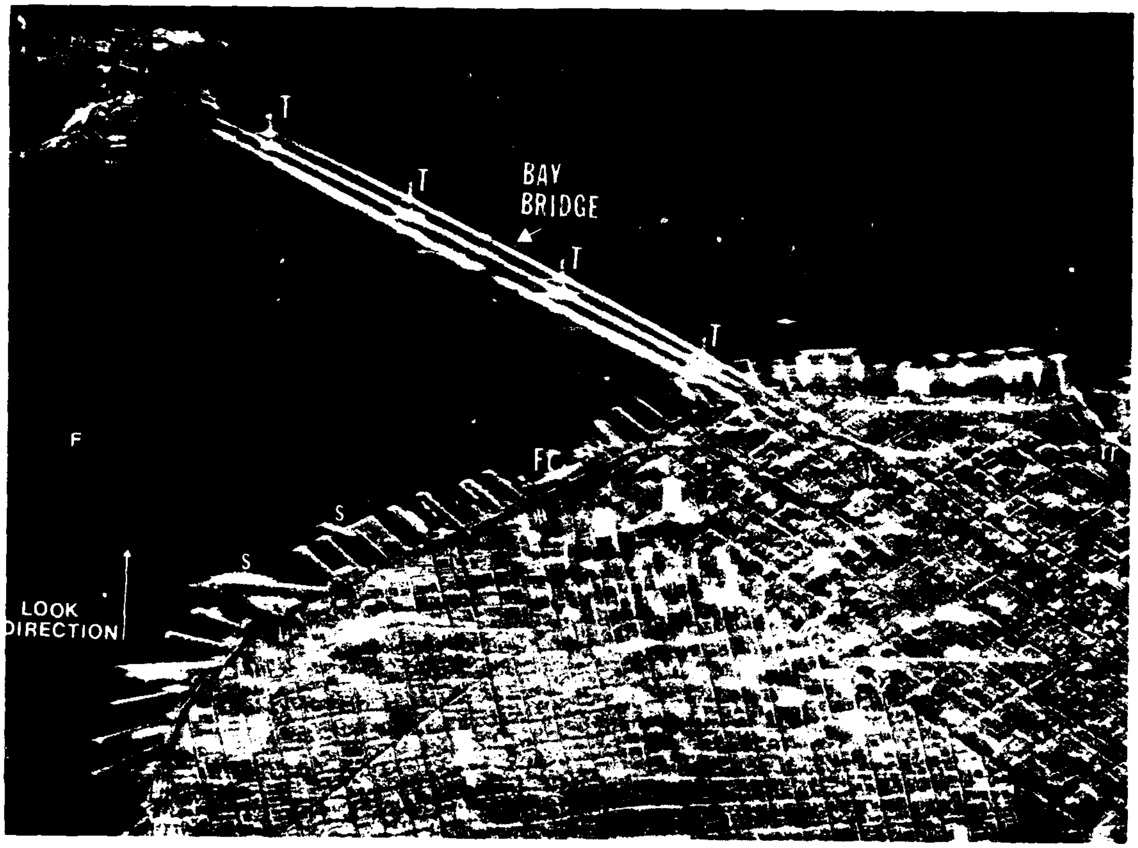
Radar Characteristics

The spectral range of the radar band extends from 8 mm to 1000 mm. The principal bands of radar remote sensing are shown in Table B.1, although it is theoretically possible to build sensors at other wavelengths. Although images from several systems are used as examples in this report, it is not intended as a comprehensive review.

Geometric properties of radar imagery are quite different from other types of imagery (Figure B-2). Whereas both thermal IR and photographic sensors produce images on the basis of angular distance from the sensor, radar systems produce images based on travel time between the transmitted pulse and the reflection. Features in the near range (closest to the aircraft ground track) have the shortest travel time, and objects in the far range have the longest. Two-way travel time is converted to spatial distance on a radar image by multiplying by the speed of light. Since time may be measured much more precisely from angular distance, high resolution radar images can be acquired from long range.

Image displays may be of two types. Slant-range displays plot each target on the image on the basis of actual two-way travel time. For this reason, image scale changes constantly throughout the range. Features in the near-range are compressed, while the far-range is expanded. On ground-range displays, an electronic device induces a delay in signal processing proportional to the depression angle, thus removing the range distortion and producing an image with constant scale except for terrain irregularities (Barr 1969).

One result of this method of imaging is the appearance of "radar shadows", which are areas of no signal return. These occur as a result of topographic obstructions in the look direction (Figure B-3). Obstructing features intercept the beam so that it never reaches the "shaded" terrain, and thus there is no return. Since the image is produced on the basis of time, rather than distance, there is a brief period when no signal is received by the antennae, and thus the shadow appears black on the image.



LEGEND

FT - FERRY TERMINAL
S - SHIPS
T - BRIDGE TOWER
rr - RAILROAD

SAN FRANCISCO, CALIFORNIA, SAR RADAR X-BAND RECONNAISSANCE RADAR 1 APRIL 71, GOODYEAR

FIGURE B-1

SAN FRANCISCO, CALIFORNIA, WITH THE BAY BRIDGE AND YERBA BUENA ISLAND (upper left)

This radar image illustrates the strong return from the buildings, piers, bridge structures, ships and urban areas. Many of the large buildings which are directly perpendicular to the radar look direction have extremely high returns. The water in San Francisco Bay is specular as are many of the roads. The profiles of several ships at the piers are obvious but the corner reflector effect from all the steel in the superstructures mask much of the ships' detail. The same is true in analyzing detailed bridge and building features. The railroad at the right side of the image is the Southern Pacific railroad yards.

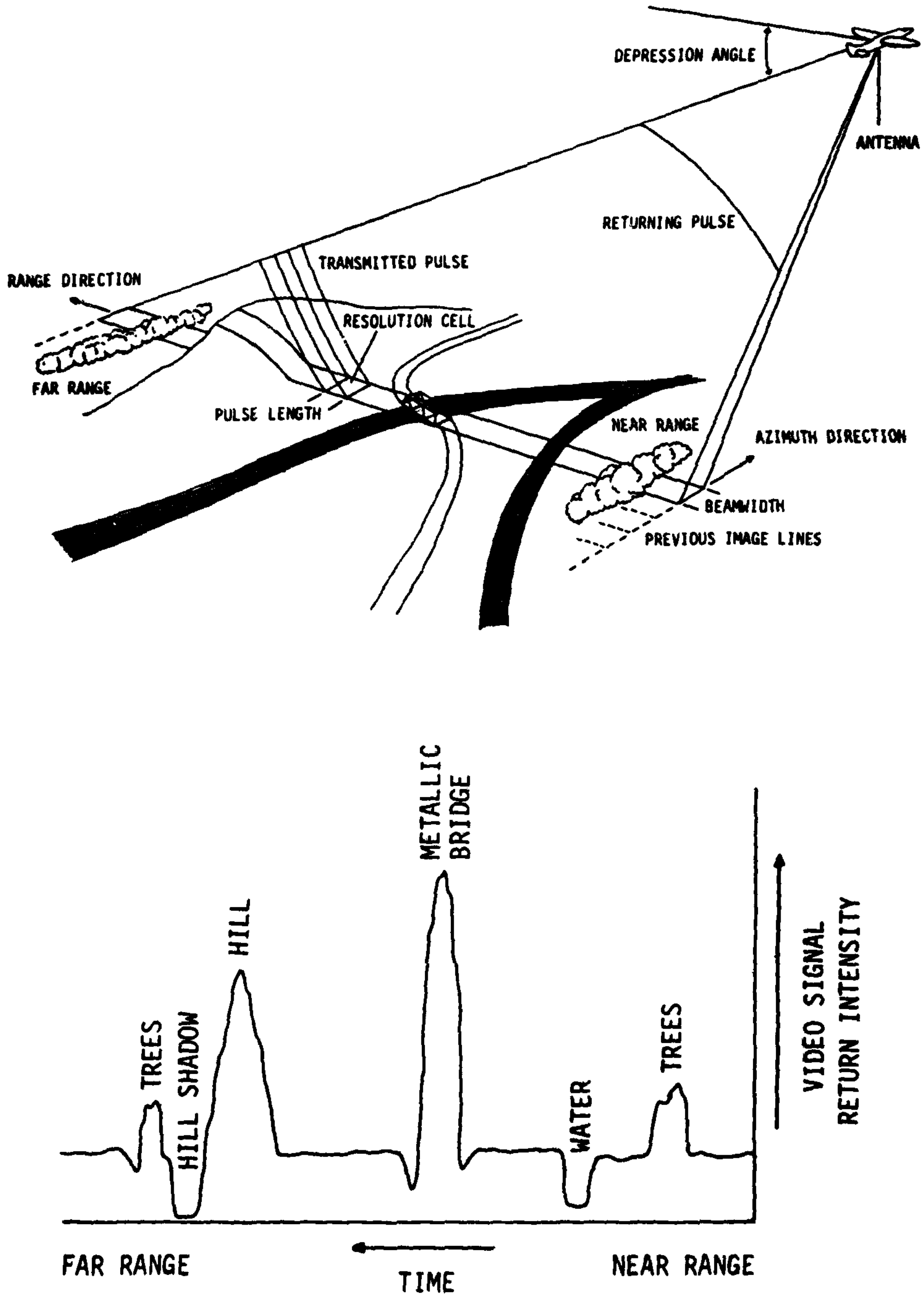


FIGURE B-2 -- SIDE LOOKING AIRBORNE RADAR (SLAR) SYSTEM OPERATION

RADAR BANDS

DESIGNATION	FREQUENCY (10^6 CYCLES/SEC)	WAVELENGTH (mm)
Ka	40,000 - 26,500	8 to 11
K	26,500 - 18,000	11 to 17
Ku	18,000 - 12,500	17 to 24
X	12,500 - 8,000	24 to 38
C	8,000 - 4,000	38 to 75
S	4,000 - 2,000	75 to 150
L	2,000 - 1,000	150 to 300
P	1,000 - 300	300 to 1000

TABLE B.1 -- PRINCIPAL BANDS OF RADAR REMOTE SENSING

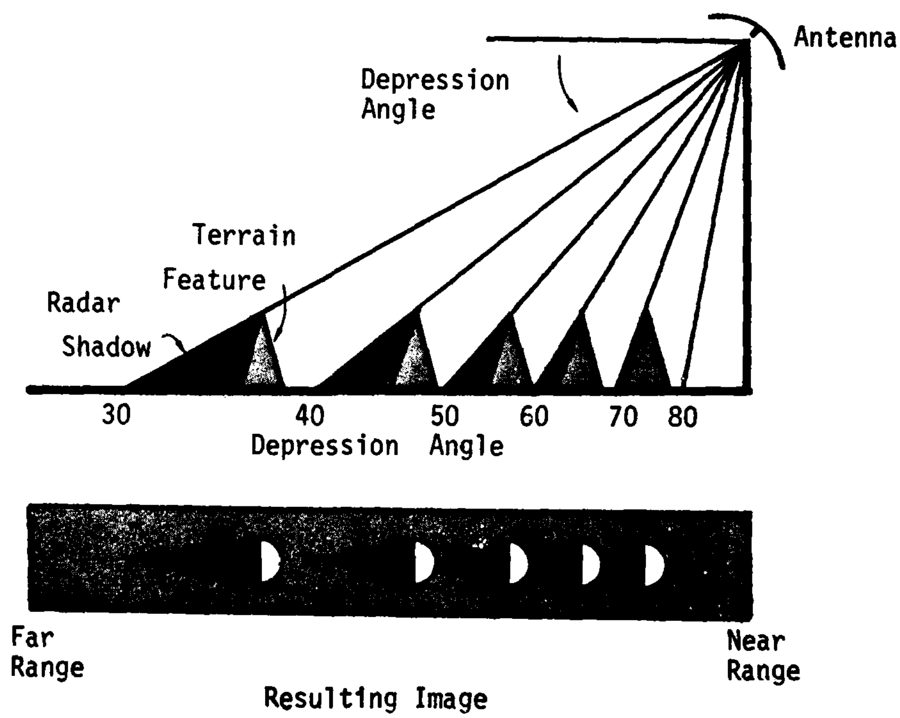


FIGURE B-3

RADAR SHADOWS OF IDENTICAL OBJECTS AT VARIOUS DEPRESSION ANGLES
(modified from Sabins, 1978)

An important engineering property of radar sensors concerns the polarization of the receiving antenna. The transmitted energy may be polarized in either vertical or horizontal planes, and upon striking the terrain, may be returned in either plane. Sensors which transmit and receive in the same plane are considered parallel polarized, while cross-polarized sensors transmit in one polarization and receive in the other. An HH is the common symbol for a system that transmits in the horizontal plane and receives in the horizontal plane. An HV is likewise used for horizontal transmission and vertical receiving. The two other common modes are VV and VH for vertical transmission with vertical and horizontal receiving respectively. While scattering of the radar beam produces depolarization in all directions, the horizontal or vertical mode captures the extremes. In general, objects which depolarize the most energy are of complex geometry with multiple reflecting surfaces oriented at random in all directions. Many types of vegetation fit into this category.

The tonal and textural qualities of radar imagery are the results of the interaction between the incident beam and surface objects. Smooth surfaces, such as paved roads, airport runways, and calm water, are considered specular reflectors. The radar beam is reflected away from the detector and such features produce a dark radar signature. Preliminary equations describing the relationship between surface roughness and radar signature have been derived by Peake and Oliver (1971). A surface may be considered smooth if:

$$h < \frac{\lambda}{25 \sin \gamma}$$

where h = height of surface irregularities

λ = radar wavelength

γ = radar beam incident angle

This inequality has been tested using radar imagery of Death Valley, California, in conjunction with field measurements of micro-relief (Schaber, Berlin and Brown 1976; Schaber, Berlin and Pitrone 1975). Natural surfaces ranging in roughness from rough, eroded rock salt (h = 29 cm) to smooth flood plain deposits (h = 0.2 cm). Radar signatures for these surface materials were predicted at X-band wavelengths, and these were compared to actual signatures from imagery. For most surfaces, the predicted signatures matched closely with actual values. In certain areas of high roughness, actual signatures were found to be darker than predicted values. It has been theorized that this was due to a high moisture content in the surface, which increased the dielectric constant and therefore increased the reflectivity of the radar beam. The potential utility of radar images for determination of surface roughness and possibly moisture content has direct application to studies of trafficability. Most studies of this type accomplished to date have taken place in arid environments, where the influence of vegetation cover is minimal.

Certain geometric shapes and materials produce unusual and unexpected signatures on radar images. Often, angular objects such as power line towers, antennaes, and small buildings produce a very bright radar signature. This is due to their function as corner reflectors. This phenomena occurs when angular objects reflect the incident order beam directed back to the sensor. Bright signatures may arise on imagery due to the strong reflection from objects far smaller in size than the theoretical resolution limits of the radar system (Figure B-4). This occurs because a sensor looks at a small area on the ground surface and produces a tone on the imagery based on the average of signatures for everything within this instantaneous field of view. If a small object is an extremely good reflector, it may raise the average for that cell to the saturation point, and thus produce a bright spot on an image which is far larger than the object alone.

Electrical properties of surface objects are also influential in determining radar reflectivity. These are generally referred to as the "complex dielectric constant". Although the effects of this property are not generally important in image interpretation, certain types of features have high values and are very highly reflective of radar energy. Such objects produce a bright signature, even though they may be below the theoretical resolution limit, as described previously. Examples include metallic objects (buildings and railroad tracks). In practice, however, it is difficult to isolate the effects of surface roughness from the influence of dielectric properties, except in controlled experimental settings.

In evaluating radar imagery the difference between like-polarized and cross-polarized is often subtle but significant. Radar images contain information on the surface roughness of the materials imaged. The subject size and dielectric constant of this top few centimeters are also significant. The like-polarized image brightness is directly proportional to the surface roughness spectrum which satisfies the Bragg conditions according to Daily et al., 1979, i.e., $\lambda = \lambda/2 \sin \theta$ where θ is the incidence angle and λ is the radar wavelength. In cross-polarized images on the other hand, the brightness is proportional to the overall roughness spectrum of the surface. When an interpreter is evaluating a like polarized image, the brightness is mainly related to the size of the scatterer relative to the wavelength. On the cross-polarized image of the same scene the brightness is mostly affected by multiple scattering, which in turn is related to the density of the scatterers per unit area. Still, it is not always possible to predict whether like or cross-polarized images will have a higher information content for a particular application.

System Summary

A summary of systems included with the report are outlined on Table B.2, Radar System Specifications. In reviewing the systems, it is noted that the terminology real and synthetic are utilized. This refers to the type of antenna beamwidth controlling system. Those SLAR (sidelooking airborne radar) systems in which the physical length of the antenna controls and beamwidth are called

RADAR SYSTEM	MANUFACTURER	WAVELENGTH & BAND		TYPE	RESOLUTION		SWATH WIDTH	POLARIZATION
					ALONG TRACK	ACROSS TRACK		
		mm			METERS	METERS	km	
AN/APS-94D	Motorola	32	X	Real	7.7 X R km	30	100	HH
L-Band	Jet Propulsion Laboratory	250	L	Syn	10	20		Transmits and Receives in both
X-L Imaging Radar	ERIM	32	X	Syn	15	15	18.5	Transmits and Receives in both
		235	L	Syn	10	10	18.5	Transmits and Receives in both
AN/APQ-102	GEMS Goodyear	31	X	Syn	10	10	37.0	HH
AN/APQ-97	Westinghouse	8.6	Ka	Real	1.7 X R km	9	10 - 20	HH and HV
Goodyear Synthetic Aperture Radar	Goodyear Aerospace		X	Syn	3	3		HH
AN/UPD-4	Goodyear RADC/IRRE	30	X	NO	DATA - - -	- - - - - - -	- - - - - - - -	- - - - - - - - -

TABLE B.2 RADAR SYSTEM SPECIFICATIONS

brute force, real aperture or noncoherent radars. Brute force systems enjoy relative simplicity of design and data processing. Because of resolution problems, however, their operation is often restricted to relatively short range, low altitude operation and the use of relatively short wavelengths. To overcome the deficiencies of brute force operation, synthetic aperture (or coherent) radar systems are used. These systems employ a short physical antenna, but through modified data recording and processing techniques, they synthesize the effect of the very long antenna. Without going into more detail here, the reader is referred to Craib, 1972, for synthetic aperture systems and to Sabins, 1978, for brute force radar. See Figure B-4, Range and Azimuth Resolution vs. Depression Angle.

Feature Summary

In evaluating the features that are of primary interest for this study, certain clues to the interpretation are evident for each sensor. A brief summary of some of the radar interpretation clues follows:

a. Vegetation: In savanna regions isolated stands of high semi-deciduous forest are easily detectable by virtue of the shadows they cast on adjacent shorter savanna. Separation of vegetation communities is based on variation in leaf, trunk, or stem geometry, canopy configuration, moisture content and growth density. Many terrain features can be deduced from the vegetation pattern on radar. Plant canopies with their varying complex dielectric constant and their microrelief often dominate the texture of SLAR image tones.

b. Open Water: Specular reflector (dark signal) on radar because of the reflectance of the incoming radar signal. Good for land-water boundary locations.

c. Relative ground moisture: Increased ground moisture increases the dielectric constant of soil almost linearly. The depth of penetration of radar waves below the surface varies inversely with the dielectric constant of the material and directly with the radar wavelength.

d. Swamps and marshes: In swamps, forested areas will have bright signatures while the water is specular or black. The swamp grass and wet land will be textured and result in an intermediate return signal. In marsh areas water-borne plants result in a textured or mottled pattern on the specular or dark water surface.

e. Urban areas: Buildings produce strong returns while streets are specular targets with no return. The variation between strong and specular returns can be used to identify the urban pattern. Many features give strong signal because of corner reflector characteristics.

f. Roads: Often specular to intermediate return, depending on surface roughness and radar system. Concrete is usually more specular than asphalt.

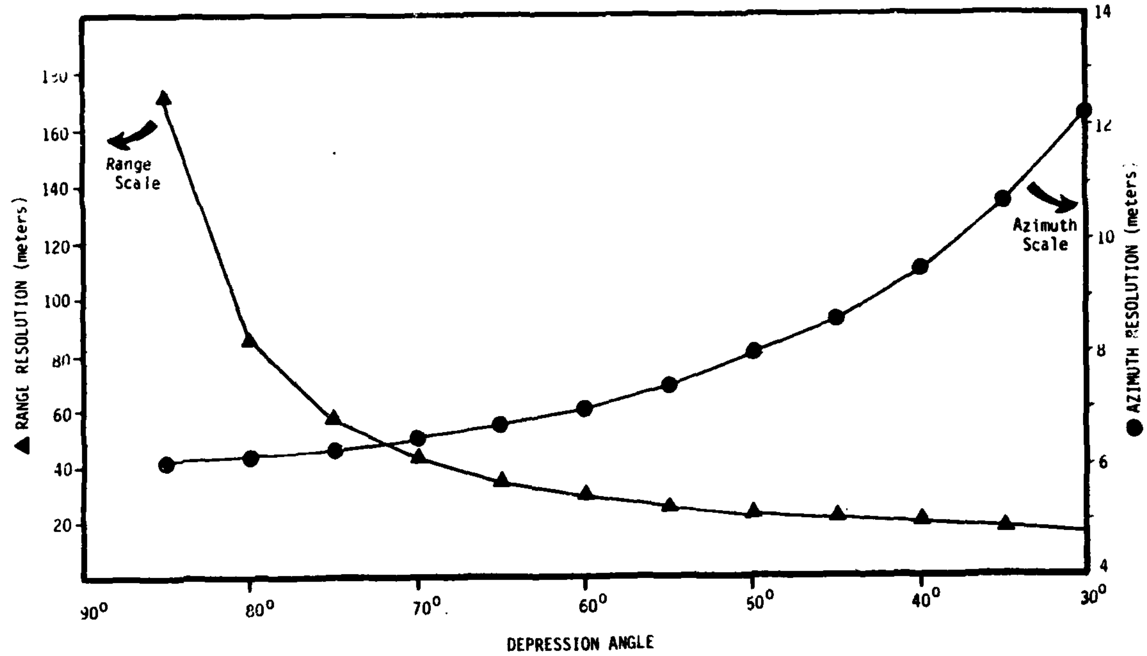


FIGURE B-4

Range and azimuth resolution of SLAR systems is a function of depression angle. As depression angle increases azimuth resolution improves, while range resolution decreases.

g. Railways: Often strong reflector because of corner reflector characteristics. Depends on system and polarization.

h. Buildings: Often strong reflectors, different materials with varying texture, roughness and moisture content result in a wide variety of signals. Many corner reflectors.

i. Bridges: Corner reflectors cause strong signal.

j. Power lines: Support towers often detectable because of corner reflectors. Line itself seldom visible.

k. Pipelines: Surface pipelines and associated equipment often form strong signal. Buried pipeline not detectable.

Satellite Radar Imagery

High resolution SAR satellite imagery from platforms such as SEASAT offers regional radar images on a repetitive synoptic basis. Although SEASAT was designed primarily for oceanographic studies, the 25 meter resolution of its L-band radar (25 cm band width) provides significant detail on land areas. Unfortunately, SEASAT-A was operational for only a short time before its sensors were disabled by a power failure; however, a digitally-enhanced image of the Los Angeles area is one of the few images available (Figure B-5).

The SEASAT radar imaged in a narrow swath in the far range, and thus employed small depression angles. This was set up to enhance detection of sea-state conditions on the basis of surface roughness variations; however, the look angles cause severe layover when imaging land areas with much relief. Consequently, mountainous areas surrounding the Los Angeles Basin are difficult to interpret because the signature consists of bright sinuous returns from ridgetops, and radar shadows.

Resolution and detail in flat lying areas is excellent in the SEASAT image when compared to visible range scanners such as LANDSAT, which orbit at comparable altitudes. The orientation of surface features with respect to the radar look direction is a primary factor affecting the radar signature. Anomolous bright blocks correspond to communities where the street pattern is arranged perpendicular to the look direction. This is also true of individual streets. Adjacent features not oriented in this way produce darker signatures.

Within urban areas, freeways, major highways, and riverbeds appear as dark specular reflectors against the mottled signature of residential, commercial, and industrial areas. In areas of moderate relief, these features are very difficult to detect or identify because of layover and radar shadowing.

Vegetation information is difficult to derive from the SEASAT radar image. The main wildland areas support dense stands of shrubs, but these are found mainly

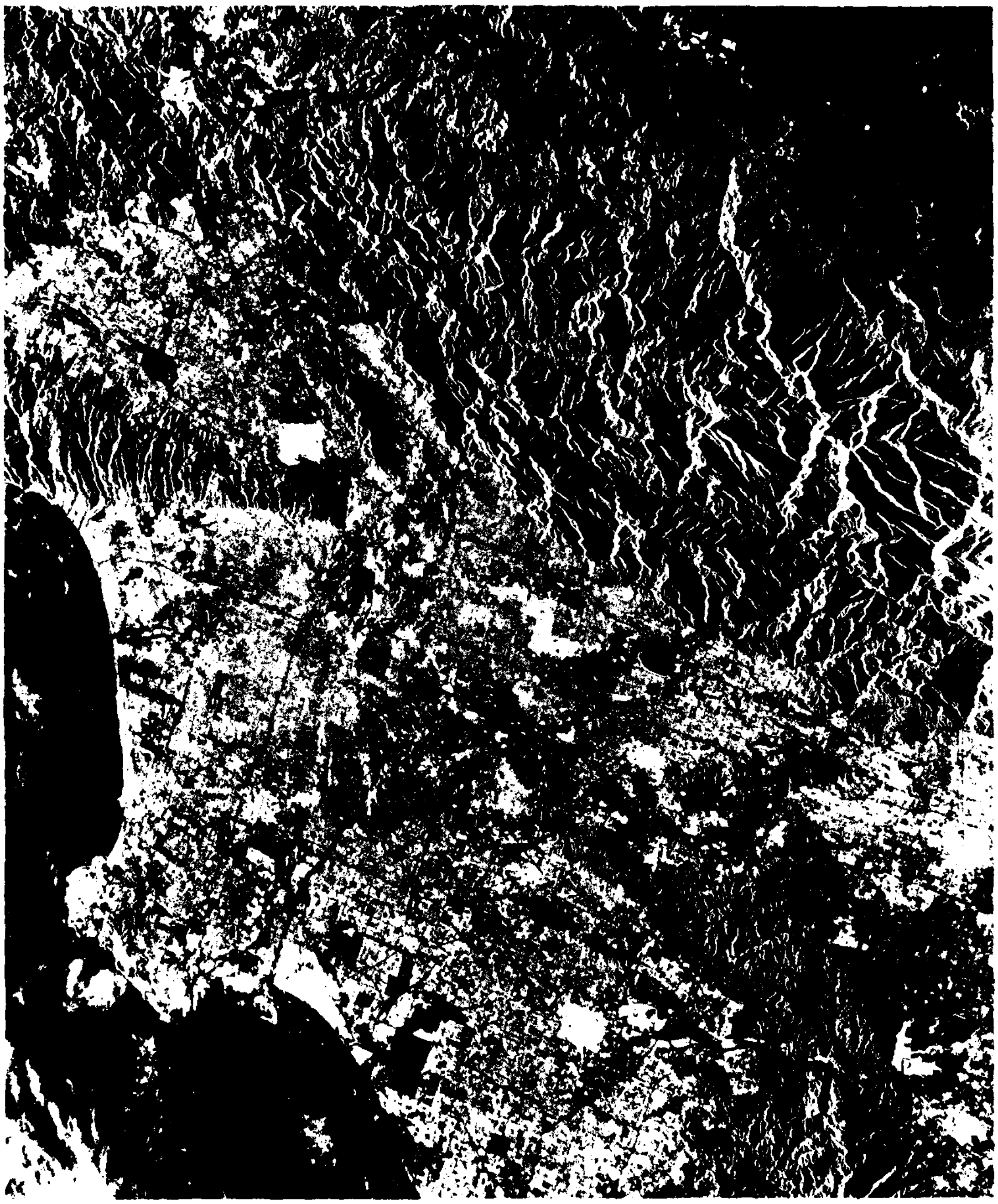


FIGURE B-5 -- LOS ANGELES BASIN, CALIFORNIA. SEASAT-A SAR L-BAND RADAR MOSAIC BY JPL SCALE APPROXIMATELY 1:520,000

July 21, 1978. Resolution of the system is on the order of 25 m. Since it was designed primarily for observations of the ocean surface, imagery of mountainous areas suffers from severe layover.

at upland sites, where relief features dominate the return. There is no detectable difference between the drought deciduous shrublands found along the coastal mountains and chaparral shrubs found on inland slopes. Although certain high elevation sites within this scene are known to support dense stands of coniferous forest, these sites may not be differentiated from other vegetation types. Neither is it possible to locate the broadleaf deciduous trees common along streambanks.

Vegetation features which may be located include coastal wetlands at Seal Beach and Marina del Rey. Both of these produce black specular signatures interspersed with strong returns from buildings scattered within the marshes. Also, agricultural lands may be identified because of the checkerboard field pattern accentuated by variations in crop types and surface roughness. Again, however, these interpretations are restricted to flat-lying areas.

Numerous powerlines are present in the image, but those may only be detected at sites where there is sufficient object-to-background contrast to resolve the lines of support towers. One of these may be seen at the Prado Dam flood (P) control basin. However, it is not visible once it enters the mountainous terrain to the north. In urban areas, it is not possible to locate powerlines because they are disguised against a background of strong returns from the urban landscape.

In general, it may be concluded that radar imagery from satellite platforms, with resolution comparable to SEASAT, may be of great utility for analysis of specialized military geographic problems. However, there are serious shortcomings for use of this type of imagery as a single data source. The ability of manual interpreters to extract information from these images is strongly influenced by the amount of topographic relief, and the information content declines drastically in mountainous regions.

APPENDIX C

THERMAL INFRARED IMAGERY

Analysis of thermal infrared (TIR) imagery requires some basic understanding of the interaction of phenomena which produce the image. A TIR image is a photographic or electronic record of the radiometric temperature of surface features when measured at specific wavelengths. These sensors use detectors which are sensitive to electromagnetic energy that cannot be seen by the human eye and convert it to forms which can be interpreted. Generally, either film or magnetic tape products are generated by these systems (Figure C-1).

Although the common definition of the infrared spectrum extends over a wide band of wavelengths, TIR remote sensing is confined to two main bands between 3.5-5.5 micrometers and 8-14 micrometers. These bands correspond to "atmospheric windows" where absorption and scatterers of energy by atmospheric gases is less severe. (Even so, TIR imagery is degraded by water, ozone, and carbon dioxide.) The thermal bands should not be confused with reflected infrared films (.7-1.3 micrometers) used for black and white and color infrared remote sensing. In the thermal bands, energy detected by the sensors is emitted by surface objects, while infrared photography images record short wavelength reflected infrared radiation.

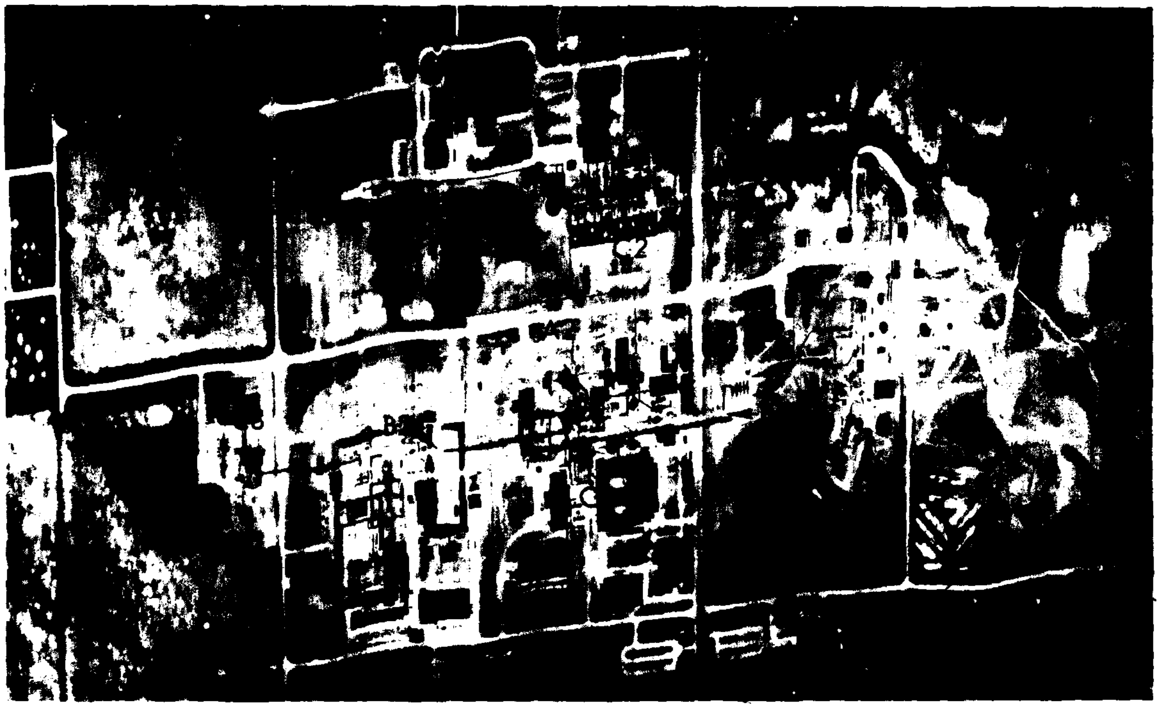
Thermal infrared energy emitted from surface objects is proportional to the kinetic temperature of the object and the emissivity of the material according to the equation:

$$T_r = \epsilon \sigma T^4$$

where T_r = radiometric temperature, ϵ = emissivity, σ = Stefan-Boltzman constant, and T = kinetic temperature in ^{o}K. The emissivity variable is an important factor and has a pronounced affect on the signature of surface targets on TIR imagery. Because $e < 1$ for all real materials, radiometric temperature is never equal to kinetic temperature and the radiation measured by the sensor does not correspond exactly to surface measurements. Two objects at the same kinetic temperature may produce different signatures on a TIR image due to differences in emissivity (Figure C-2). Therefore, interpreters must be aware of the fact the TIR sensors do not measure sensible heat alone. (For more detailed discussion, readers are referred to Sabins, 1978; Mel, 1975; and Bastuscheck, 1970).

TIR Interpretation

The actual mechanics of TIR imaging are also an important consideration for interpretation. Images are generated by electro-optical scanners mounted in various types of aircraft. Lateral coverage is obtained by scanning terrain from side to side, and forward coverage is provided by the motion of the aircraft (Figure C-3).



A -- SUBSURFACE STEAM PIPE
B -- VALVE POINT ON HEATED PIPE
C -- HEAT BLOOMING FROM ROOF VENTS

FIGURE C-1 -- MANCHESTER, TENNESSEE, THERMAL INFRARED, AAS-18A, 15 SEP 75, ARNOLD ENGINEERING, FLIGHT ALTITUDE 1500 FEET, TIME 0450, RADC/IRRE.

FIGURE C-1 ENGINEERING PLANT, MANCHESTER, TENNESSEE

The industrial site shown in this TIR image has numerous examples of high and low emissivity which are clearly visible. Although no accompanying radar or panchromatic photography was available from the source (Rome Air Development Center) the image illustrates some significant features which warrant its inclusion. The image was collected by the USAF on a MAIRS (Medium Altitude Infrared System) scanner which is a modified AN/AAS-18A Texas Instrument scanner. The signal shows a good sensitivity to radiant energy differences. This results in a clear definition of objects to their background. Features in this image which are clearly outlined include: pipelines, pipeline valves, roads, buildings, heater vents, and storage facilities.

It should be remembered that the lighter shades of gray represent higher levels of radiant energy. The darker tones represent relatively lower radiant energy. For most of the objects this can be related to surface temperature. It should be remembered that the evaluation was made with no ground truth or surface knowledge with the exception of location, date, time of day, flight altitude, and general activity. Some sinusoidal distortion is indicated by the road pattern.

The evaluation of this image is broken down into:

A. Subsurface heat pipes
B. Valve locations along the pipes
C. Heat blooms issuing from roof vents

At the pipe locations indicated by the A one can see the surface expression of the heating of the surface material. At A1 and A2 the soil appears to cover the pipe (or vent) while at A3 the pipe appears to be covered by a concrete walkway. The A3 pipe is leaking excessive heat on the September morning when this image was collected. Along the piping system, several of the valves are obviously closed, stopping the flow of the heated materials within the pipes (see B1 and B2). Roof vents in the buildings at C1, C2, and C3 show the results of heat escaping. The pattern of the escaping heat of C1 indicates the breeze blowing from right to left. The building near the top of this image appears to be better insulated than the ones in the lower center.

The pipes just above the B1 are all dark with the exception of several lighter junctions along the pipe. There is a good possibility that the pipe is well insulated, causing this darker tone. Where the pipe turns, another type of fitting or valve is apparent because of the lighter or relatively warmer tones. These fittings do not have the same covering or insulation so the material within the pipe is heating them up. This could be a clue to what the pipe might be carrying. On the far right side of the image a hot liquid, probably water, is being pumped into two ditches which meet, part under several roads in pipes and then drain into the field at the extreme right. This is probably cooling water from the test facilities.

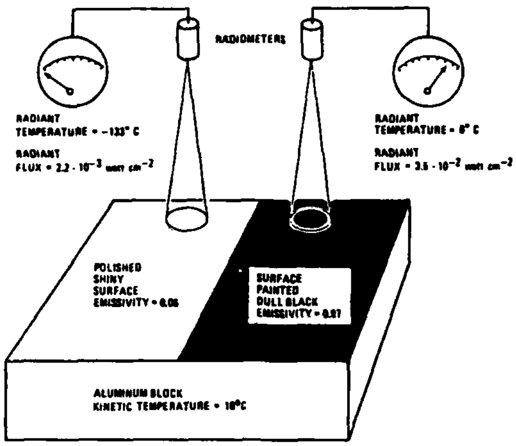


FIGURE C-2 -- EFFECT OF EMISSIVITY DIFFERENCES ON RADIANT TEMPERATURE
Kinetic temperature of aluminum block is uniformly 10°C. Different emissivities cause different radiant temperatures that are measured with radiometers. "From Remote Sensing: Principles and Interpretation by Floyd F. Sabins, Jr. W. H. Freeman and Company. Copyright © 1978."

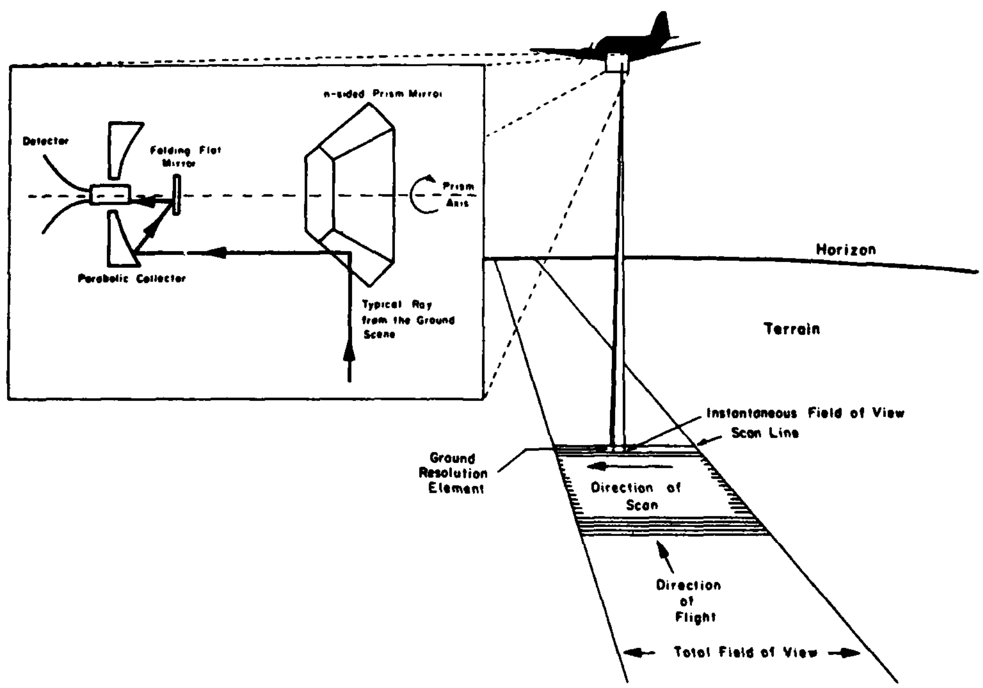


FIGURE C-3 -- IMAGING TIR SENSORS COVER TERRAIN IN A SERIES OF PARALLEL SCANS
Incoming radiation is handled as shown in the inset. Data output from the detector may be displayed on a TV screen produced directly on photographic film (via a CRT) or, more commonly, stored on magnetic tape.
(From Estes, 1974)

There are a number of systematic distortions which affect the geometric fidelity of TIR images. The most serious result from the differences in distance, scale, and resolution between the ground track of the aircraft and the far range of the scanner (Figure C-4). Because of this distortion, scale of most TIR images changes continuously across the width of an image, but remains constant along the length. Sinusoidal distortion of linear objects is one obvious result. The transformation of other shapes is more complex. Processing of TIR images to reduce or remove distortion is now a standard practice with most systems.

Resolution of TIR systems consists of two components: spatial and temperature. Various commercial systems available have different specifications; however, in all of these the spatial resolution is a function of sensor altitude and its angular field of view. A typical system has an angular field of view of about 1 milliradian, which results in an instantaneous ground spot size of 1 foot in diameter per 1000 feet of altutude. Temperature resolution may be varied with system controls. Two primary controls are system gain and DC level, which are analogous to the contrast and brightness of a television set. By using a high gain setting, greater temperature resolution is achieved, but generally system noise increases correspondingly, and the overall image is degraded. Many systems achieve thermal resolution of 0.5°C.

Survey Operations and Image Appearance

Timing of TIR surveys is of critical importance to image interpretation. During daylight hours, most images are dominated by the effects of differential heating due to sun angle, topography, and surface feature orientation. While specific applications may employ images collected independent of the time of day (e.g., ocean temperature), many investigators have reported superior results from nighttime imagery (McLerran, 1967; Stingelin, 1968; Sabins, 1978). After the sun goes down, most surface objects begin to cool at rates dependent on their heat capacity, thermal inertia, and thermal diffusivity. The range of temperatures present in a given scene tends to increase during this period until pre-dawn when maximum thermal contrast occurs. Again, specific applications may call for imagery from a specific time of day, but for general reconnaissance, pre-dawn coverage may be preferred.

Multi-temporal coverage of the same terrain may provide a great deal more information than a single pass because it allows the interpreter to compare the signatures of surface features in different thermal regimes. Physical properties of objects of interest include their heat capacity, thermal inertia and radiometric temperatures which may be deducted from images obtained at different times of day. For example, on daytime imagery, surface water generally appears dark because it is cooler than dry land. At night, dry areas lose heat more rapidly than water (higher thermal diffusivity, lower thermal inertia) and so water generally appears white (warm) in image positives. At certain times, both water and land may be at the same temperature (crossover points) and will be difficult to differentiate on the basis of thermal properties alone.

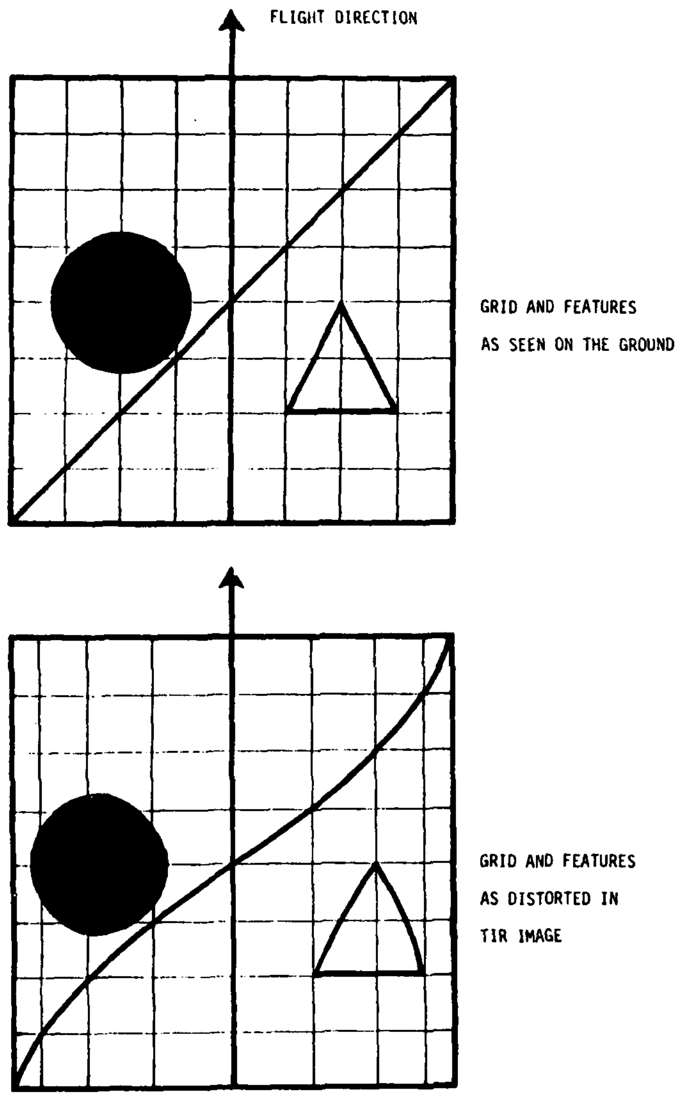


FIGURE C-4 -- THERMAL INFRARED SCANNER DISTORTION

Other conditions which may directly alter the appearance of TIR images include the effects of surface wind, humidity, cloud cover, and electronic interference. Sabins (1973) has reported that high surface winds may produce parallel curvilinear lines of alternating light and dark tones over large areas of an image, or short plumes with a warm signature in the wind shadow behind obstructions. The effects of humidity include general lowering of both spatial and thermal resolution, while heavy overcast causes further reduction of thermal contrast. Clouds produce a characteristic warm and cold patchy pattern, while rain obscures the image entirely.

Scanner Systems

The scanner systems described are limited to those used for collecting imagery utilized on this report. Those interested in a more technical and complete list are referred to The Infrared Handbook, Wolfe and Zissis, Eds. 1978. The thermal scanners build up a two-dimensional record of radiant temperature data for a swath beneath the aircraft as shown in Figure C-3. The scanner contains a rotating mirror assembly that moves the detector along scan lines that run perpendicular to the direction of flight. Close observation of the scanner imagery reveals these lines. Processing techniques are used to remove or lessen the affect of these lines from magnetically taped data. This makes interpretation and evaluation easier and more accurate. The detector signal along each scan line is related to the radiant energy emitted from ground objects along the scan line. The plane's forward motion causes a new strip of the ground surface to be covered by successive scan lines. The signal for each line may be used to modulate the intensity of a single-line cathode ray tube or as an input to a tape recorder. In the instance when the cathode ray tube is used, an image line is exposed on black and white film. By the continuous exposing of the scan lines side by side, the image is built up to what the interpreter utilizes. Although the tape data must be returned to a playback facility, the information is in a format that can be computer processed. The ability to computer process thermal scanner data makes the data available to a series of analysis capabilities. These are not always available when using film. The scanners used are described in Table C.1.

MANUFACTURER	TEXAS INSTRUMENTS	DAEDALUS	ERIM	*MAIRS	HRB SINGER	BENDIX T/M	HONEYWELL
Scanner Model	RS-310	DS-1200	M7	Modified Texas Instrument AAS-18	Reconofax XIII	LN-3	No Data
Scan Lines/ sec Rate of Scan (RPM)	200	80	100		800	100	
Scanwidth-Degrees	90^o	77^o	90^o	90^o	120^o	120^o	
Resolution Element Mrad	1.5	2.5	2.0		1 and 2 mr. (in same Dewar flask)	2.5	
Method of Recording	Film	Tape Recording Film Optional	Tape Rec.		Film	Film Tape Recorder Optional	
Sources of Specification	IRIA	Mfg. Lit.	Mfg. Lit.		Mfg. Lit.	IRIA	

TABLE C.1 -- INFRARED SCANNER SPECIFICATIONS

APPENDIX D

PANCHROMATIC PHOTOGRAPHY

Panchromatic film is sensitive in the 0.36 - 0.72 micrometer spectral range. This includes visible radiation and portions of the UV and IR spectral regions. The film records the light reflected by a surface (determined by albedo), the ratio of the reflected energy to the incident energy. Dark surfaces have a low albedo and light surfaces have a high albedo (see Figure D-1).

When the film is processed and a print is made, images appear on the positive in varying shades of gray. Each tonal value corresponds to the density (spectral reflectance) of an object's color response (wavelength) as perceived by the human brain; i.e., photographs retain familiar qualities of "lightness" and "darkness" although color is excluded. The contrasts in tonal values between adjacent features are the basis for image interpretation. (Manual of Remote Sensing, 1975).

The high resolution capability of panchromatic imagery allows the identification of small objects and features from small-scale imagery. Also, when relief displacement is taken into account, distances and height can be measured accurately on vertical and oblique imagery.

Factors affecting the photographic image are both natural and operator controlled. Natural factors are variable with time and location and include sun angle, atmospheric haze and cloud cover, and object color. The operator controls the focal length of the lens, flight altitude, camera angle, film and filter selection.

Interpretation Elements

Tone

Different objects reflect, emit, and transmit various amounts and wavelengths of energy. These differences are recorded as tonal variations on an image. Without a difference in tone between an object and its background, there would be no perceivable image. Contrasting gray values are the basis of image interpretation.

The usefulness of photographic tone depends upon the problem considered and how it is used with other interpretation elements. For example, distinguishing the differences between two tree types of similar reflectance may be impossible based on tonal values alone, but becomes easier when the element of texture is also incorporated.

Panchromatic aerial photo, March 22, 1976. Source: Teledyne Geotronics.

FIGURE D-1 - A PANCHROMATIC AERIAL PHOTO OF LONG BEACH, CALIFORNIA

Labelled features are: A - Airport, B - Drive-in theater,
C - Residential, D - Park with deciduous, E - Oil tank farm,
F - Industrial park, G - Water body.

Texture

Tonal repetitions in groups of objects create texture. Often, the objects are too small to be discerned individually, so the visual impression of "roughness" or "smoothness" is a valuable aid in interpretation. Within a certain range of scales, the texture of a group of objects may be distinctive enough to indicate the identity of the group.

Pattern

Pattern (orderly arrangement or repetition) is especially characteristic of man-made objects. Cultural features are particularly conspicuous in aerial images because they consist of straight lines or other regular configurations, but pattern also occurs in natural features such as drainage, fault, and outcrop patterns. The configuration of cultural features may be an indication of function; sharp, angular contacts denoting something different from gently curving lines. For example, streets with sharper curves and intersections can be distinguished from railroads which necessarily have more gentle profiles.

Site

When examining a site, noting the relationship between factors such as geology, topography, and man's impact, is helpful in interpretation. For example, certain structures such as radar stations are more likely to be found on high points than in lowlands, just as some vegetation types prefer flatlands to steep mountainsides.

Association

The relation of a feature to its surroundings, whether natural or man-made, becomes important when a single object may not be distinctive enough to allow its identification by itself. Some objects which are very commonly associated tend to confirm the identity of the other, such as farms and silos, road intersections and gas stations, utility towers and power lines, and pumping stations and buried pipelines.

Size

The size of a feature is a useful clue to its identity, and by measuring an unknown feature and/or comparing it to a known feature on an aerial photo, the range of possibilities is narrowed considerably.

Shape

Some features can be identified solely on the basis of their distinctive form, and the plan or top view is an important indication of an object's structure, composition, and function. Shape is important in recognizing constructional land forms, such as volcanic cones and river terraces.

Shadow

Shadows work for and against the interpreter as they may reveal silhouettes, yet hide some detail. Cast shadows can aid in determining the size and shape of an object. They are especially helpful if the object is small or of similar tone when compared to surrounding areas. The sharp boundaries and shapes of the shadows therefore permit the identification of otherwise unrecognizable objects.

Interpretation Techniques

Monocular Analysis

Distances or depth are perceived on the basis of (1) relative sizes of objects, (2) hidden objects, (3) shadows, and (4) differences in focusing of the eye required for viewing objects at varying distances.

Generally, however, only two dimensions can be perceived. Still, much detail can be detected on a single panchromatic image.

Stereoscopic Analysis

This is one of the most used interpretation techniques in which the interpreter creates a vertically exaggerated three-dimensional model of terrain by viewing overlapping imagery.

Accurate height, shape, and relief measurements can be made on panchromatic imagery by viewing the imagery stereoscopically and using parallax equations to take into account the principles of relief displacement and stereoscopic parallax.

The interpreter should be aware of an effect known as a pseudoscopic illusion. Reversal of relief occurs if the left and right hand photos of a stereo pair are transposed. This effect may also occur when viewing a single photo at different orientations; the correct relief impression usually occurs when shadows fall toward the observer.

Densitometric Analysis

Density is a measure of the opacity or darkness of an image. A photograph can be considered a visual record of the response of many small detectors to energy incident upon them. These detectors are the silver halide grains in the film emulsion. The energy causing this response is referred to as the film exposure. Since all areas on the film are exposed for the same period of time, the differences are caused by irradiance differences between elements. These irradiance differences are in turn caused by reflectance differences among scene elements. One measure of the darkness or lightness of a given point on a film is opacity. Opacity is determined through measurement of a film's transmittance. Although transmittance and

opacity describe the darkness of a film emulsion, it is often convenient to work with a logarithmic expression, which is density. The human eye responds to light levels nearly logarithmically, so density is a convenient expression. There is a nearly linear relationship between image density and the film's visual tone.

The densitometer analysis of film transparencies consists of measuring density by shining light through the film. The amount of light which is transmitted through the film forms the basis of the film density analysis. The darker an image is, the smaller the amount of light that is allowed to pass; the lower the transmittance, the higher the opacity and the higher the density. The processing of the film (chemicals, time, materials) can have a definite added effect to the density readings obtained. For those interested in the many variables involved, the Manual of Remote Sensing, 1975, is an excellent starting point.

APPENDIX E

LIST OF FEATURE IDENTIFICATION KEYS

VEGETATION - Wooded and scrub--deciduous and evergreen

1. Green deciduous - warm signature on TIR nighttime images. During the day transpiration of water vapor lowers the leaf temperature causing vegetation to have a cool signature relative to the surrounding soil.

2. Conifers - on TIR relative high nighttime and low daytime radiant temperature is apparently not related to water content. The composite emissivity of the needle cluster making up a whole tree approaches that of a black body.

3. Dry vegetation - on TIR vegetation such as crop stubble appear warm on nighttime imagery in contrast to bare soil, which is cool. The dry vegetation insulates the ground to retain heat and causes the warm nighttime signature.

4. Radar backscatter from a vegetation canopy consists of contributions by the canopy itself as well as a possible component contributed by the underlying soil. The scattering behavior of a vegetation canopy is governed by its geometrical and dielectric properties, specifically the three dimensional variation of the complex dielectric constant within the canopy.

5. Depolarization effects on radar are much stronger from vegetation than from bare ground. The leaves, twigs and branches cause the multiple reflections that to be responsible for depolarization. In some cases this can be used for vegetation differentiation.

OPEN WATER

Calm water is a specular target, i.e., transmitted radar energy is almost totally reflected at an angle equal and opposite to the incident angle. When located in the extreme rear range, water may produce a bright return, but in most cases it has a dark signature.

The signature of water in a thermal IR image is dependent upon the time of day. During the day when soils and rocks heat up, water retains a cooler surface and has a darker signature. At night, surface temperatures are reversed and water images warmer than soils and rock. This is due to the effects of convection in maintaining a body of water at a relatively uniform temperature.

The signature of water on a panchromatic image varies from dark to bright. Light will penetrate calm water to some degree thereby decreasing reflectance. Turbid or rough water causes more reflectance and a brighter tone.

GROUND MOISTURE

1. Radar return depends on:

   - scattering characteristics
   - roughness
   - moisture
   - composition

   Dependence on surface roughness is minimum for a C-band radar operating in the 4.25-5.25 GH_Z band according to Ulaby et. al., 1977. The incidence angle in the 7^o - 17^o range and HH polarized also represent optimum parameters. Correlation and sensitivity between the scattering coefficient and soil moisture is maximum for these parameters.

2. Ideal parameters of measuring device:

   - Minimum dependence on vegetation cover
   - Minimum dependence on surface roughness
   - Minimum dependence of soil composition
   - Maximum correlation between scattering coefficient and soil moisture
   - Maximum sensitivity to changes of scattering coefficient to changes in soil moisture

3. In TIR moist ground is cooler than dry ground, both day and night, because of the cooling effect as absorbed water is evaporated. The evaporation effect produces cool signatures on thermal infrared images.

SWAMPS AND MARSHES

1. Swamp boundaries, extent of surface water and drainage patterns can be detected on photography. In addition, seasonal imagery can be used to map evergreen versus deciduous canopy and understory. It is also possible to descriminate among several of the more discreet deciduous communities. Swamp vegetation is an excellent indicator of the hydrologic regime.

2. TIR can be effectively used to delineate the water land boundary when sufficient soil moisture difference is present. Also many of the swamp vegetation types emit IR energy at various levels depending on their physical make-up and the time of day.

3. Radar return from swamp and marsh areas depend to a great extent on vegetation canopy, bandwidth, depression angle, and polarization. The depth of penetration of radar waves below the surface varies inversely with the dielectric constant of the material and directly with the radar wavelength.

URBAN AREAS

On all types of imagery, urban areas are easily recognized by distinguishing road and building patterns. On high resolution panchromatic photographs, individual houses can be seen.

On radar images, urban areas generally produce a strong return. This is due to the ability of the buildings to act as corner reflectors. Another reason for their bright signature is that the radar system "sees" these areas as being rough and there is more back-scatter toward the antenna.

Because of its relation to temperature, the thermal IR signature of an urban area varies with time of day and season. Also, building materials affect the tone which appears on the image, but building shapes and road configurations remain constant and allow easy identification of urban areas.

ROADS

Due to the specular nature of roads, they have a weak return and appear dark on radar imagery. They may have curbs or guardrails which can produce bright images which, by their presence, can help to distinguish a road from adjacent smooth terrain.

On a thermal IR image, the signatures of roads vary with time of day and building material. For example, during the day when solar heating occurs, concrete images darker than asphalt. After sunset, the asphalt cools faster than the concrete and so appears darker.

The linear or curvilinear expression of roads on panchromatic imagery is usually well defined, with the resulting tone being a function of the albedo of the road surface.

RAILWAYS

On panchromatic photos, railways may be similar to roads in their linear nature, but several clues can aid the interpreter in differentiating between the two. For example, single railways are narrower than roads; roads can have such configurations as hairpin curves which railways cannot; roads often intersect at a a 90° angle while two railways branch off from each other in a gently curving manner.

The dark signature of railways is common in thermal IR images. This is due to the low emissivity of the metal rails which causes them to have a low radiant temperature.

Railways, because of their metallic structure, produce a strong return and therefore a bright signature on radar imagery.

BUILDINGS

The high resolution of panchromatic photography allows the detection of individual buildings with image tone dependent upon the reflectivity of the roof material.

In radar imagery, buildings often act as corner reflectors. This causes a strong return and resulting bright signature. Also, metal-roofed structures can produce a strong return, but individual building configurations may be difficult to discern.

Building signatures on thermal IR images vary widely with a number of factors, including time of day, roof material, and season. One building type whose signature is most constant is the metallic structure. Because of its low emissivity, it images cooler than other types of buildings both night and day.

BRIDGES

Bridges are usually clearly seen on panchromatic photographs. The presence of a bridge is often enhanced by the shadow it casts on the ground or water below.

Bridges most often have a bright signature on radar imagery. This is due to their ability to act as corner reflectors and also because many bridges have metal guardrails or supports.

The signature of a bridge on thermal IR imagery is variable and dependent upon the radiant temperature of the bridge as compared with the area it crosses. For example, a bridge crossing water would be better defined than a highway overpass where the road it crosses is made of similar materials. In this case, cooler shadows cast can accentuate the presence of a bridge.

POWERLINES

Powerlines themselves are often difficult to detect. On panchromatic imagery, the primary indication that these lines are present is often the shadows cast by support towers.

On radar images, support towers can act as corner reflectors and in areas where these towers are metallic, a bright signature results.

If support towers are metallic, they will produce a cool signature on thermal IR images. Also, the shadows cast in a daytime image will have a dark tone and powerlines may be located in this manner.

PIPELINES

It is assuming that pipelines are buried and that the only place they are visible would be crossing rivers or barriers.

1. The location of pipelines must be determined by secondary evidence other than their visual detection.

   Evidence such as: cuts in vegetation, soil disturbances, moisture variances, pumping stations, pipeline roads, thermal inertia variances in survace material, straight line access cut through urban areas. Most of these features can be camouflaged to some extent when necessary. In this study emphasis was placed on the most likely of the types of evidence stated above.

2. Any metallic pipeline will give a strong radar return if it is lying on the surface. Any pumping stations should give strong corner reflector signals also. Painting or wrapping of the pipeline will change the expected return to varying degrees.

3. On TIR a pipeline or pipeline train may leave an obvious lineament that could show up as an emmitance anomoly.

APPENDIX F

GLOSSARY OF TERMS

- A -

ABSORPTION: (1) The process by which radiant energy is absorbed and converted into other forms of energy. Absorption takes place only after the radiant flux enters a medium and thus acts only on the entering flux and not on the incident flux, some of which may be reflected at the surface of the medium. A substance which absorbs energy may also be a medium of refraction, diffraction, or scattering; these processes, however, involve no energy retention or transformation, and are to be clearly differentiated from absorption. (2) In general, the taking up or assimilation of one substance by another. (3) In vacuum technology, gas entering into the interior of a solid.

ALBEDO: (1) The ratio of the amount of EMR reflected by a body to the amount incident upon it, often expressed as a percentage, as the albedo of the Earth is 34 percent. (2) The reflectivity of a body as compared to that of a perfectly diffusing surface at the same distance from the Sun, and normal to the incident radiation. Albedo is sometimes used to mean the flux of the reflected radiation as, the Earth's albedo is 0.64 calorie per square centimeter. This usage should be discouraged. Albedo may refer to the entire solar spectrum or merely to the visible portion.

ANGLE OF DEPRESSION: (1, general) any angle measured from the horizontal to an object below the observer. (2, radar) The angle formed by the horizontal plane and the line of the radar beam to a ground feature.

ANGLE OF INCIDENCE: The angle at which EMR strikes a surface as measured from the normal to the surface at the point of incidence (limits: 0 to 90 degrees).

ANGLE OF REFLECTION: The angle which EMR reflected from a surface makes with the perpendicular (normal) to the surface.

AZIMUTH: (1, general) The direction of a line given as an angle measured clockwise from a reference direction, usually north. (2, radar) Direction at right angles to the antenna beam. In side-looking radar, the direction parallel to ground track.

- B -

- C -

CELL: An area on the ground from which EMR is emitted or reflected.

COHERENT RADAR: A radar system in which the phase relation between transmitted and received signals is measured and utilized.

CONTRAST (photography): The difference in light intensity between highlights and shadows. The ratio of reflecting power between the highlights and shadows of a print determines the parts compared. The amount of contrast in a finished photograph may be attributed to several factors: the exposure given the negative, the filter used, the type of film, the duration of development, the duration of exposure and development in printing, the paper used in printing, and the developer used both for the negative and the print.

CORNER REFLECTOR (dihedral): A dihedral (two-sided) corner reflector is formed by two intersecting flat surfaces perpendicular to each other. Radar energy striking one of these surfaces is reflected back to the antenna via the other surface. Frequently used on control points in radar surveys.

CROSS-POLARIZED: Radar return pulse in which the polarization direction is normal to the polarization direction of the transmitted pulse. Images recorded with cross-polarized energy may be HV (horizontal transmit, vertical return) or VH (vertical transmit, horizontal return).

- D -

DENSITY (abbr. D): A measure of the degree of blackening of an exposed film, plate, or paper after development or of the direct image (in the case of a *printout material*). It varies with the use of scattered or specular light.

DEPRESSION ANGLE: See ANGLE OF DEPRESSION

DIELECTRIC CONSTANT, COMPLEX: The combined effects of dielectric and conducting or other loss properties of a material may be stated together by use of the complex dielectric constant. This is a complex number in which the real part is the true dielectric constant (absolute or relative) and the imaginary part is the loss term. It comes about by writing Ampere's Law for a time-harmonic field and combining the conduction current (loss) term with the displacement current term into a form like that for a lossless medium. It is usually written $\varepsilon' - i\varepsilon''$. If only conduction currents cause loss, $\varepsilon'' = \sigma/\omega\varepsilon$. The complex dielectric constant can be used to obtain a complex index of refraction. Interpretation of the latter is different from the definition given here for index of refraction, but too involved to present in a Glossary.

DIFFRACTION: The propagation of EMR around the edges of opaque objects into the shadow region. A point of light seen or projected through a circular aperture will always be imaged as a bright center surrounded by light rings of gradually diminishing intensity in the shadow region. Such a pattern is called a diffraction disk, Airy disk, or centric.

DIGITAL IMAGE PROCESSING: Computer manipulation of the digital values for picture elements of an image.

DIGITIZATION: The process of converting an image recorded originally on photographic material into numerical format.

DIURNAL: Having a period of, occuring in, or related to a day.

DOPPLER EFFECT: A change in the observed frequency of EM or other waves caused by relative motion between the source and the observer.

DOPPLER RADAR: A radar which detects and interprets the Doppler effect in terms of the relative volocity of a target.

- E -

ELECTROMAGNETIC RADIATION (EMR): Energy propagated through space or through material media in the form of an advancing interaction between electric and magnetic fields. The term radiation, alone, is used commonly for this type of energy, although it actually has a broader meaning. Also called electromagnetic energy.

ELECTROMAGNETIC RADIATION, (coherent): EMR is coherent when it is based upon a single-frequency sinusoidal variation.

EMISSIVITY (symbol ϵ): A special case of exitance, a fundamental property of a material that has a specular surface and is sufficiently thick to be opaque. One may further qualify it as spectral emissivity in reference to a specific bandpass. The suffix 'ity' implies a property intrinsic with a given material, a limiting value.

ENHANCEMENT: The process of altering the appearance of an image so that the interpreter can extract more information. Enhancement may be done by digital or photographic methods.

- F -

FREQUENCY: Number of oscillations per unit time or number of wavelengths that pass a point per unit time. The frequency bands used by radar (radar frequency bands) were first designated by letters for military secrecy. Those designations are:

RADAR BANDS

DESIGNATION	FREQUENCY (10^6 CYCLES/SEC)	WAVELENGTH (mm)
Ka	40,000 - 26,500	8 to 11
K	26,500 - 18,000	11 to 17
Ku	18,000 - 12,500	17 to 24
X	12,500 - 8,000	24 to 38
C	8,000 - 4,000	38 to 75
S	4,000 - 2,000	75 to 150
L	2,000 - 1,000	150 to 300
P	1,000 - 300	300 to 1000

- G -

GROUND INFORMATION: Information derived from ground data and surveys to support interpretation of remotely sensed data.

GROUND RANGE: The distance from the ground track (nadir) to a given object.

GROUND RANGE IMAGE: A sidelooking radar image in which objects at the reference elevation are located at distances corresponding to their separation on the terrain. Compare slant range image.

GROUND RETURN: Radar echoes reflected from the terrain. Also called ground clutter, land return. Echoes from the sea are called sea clutter or sea return.

- H -

HOLOGRAPHIC FILM RECORDER: A rectangular array of mini-resolution photosensitive material. Each hologram 1 mm in diameter may contain 10,000 or more bits of information. The real images are binary dot patterns with a laser beam reconstructing the image and projects it onto an array of photodiodes which read a pattern of zeroes and ones.

- I -

IMAGE BRIGHTNESS (RADAR)-Directly proportional to the surface roughness at the scale which satisfies the BRAGG conditions (i.e., $\lambda = \lambda/2 \sin\theta$ where θ is the incident angle and λ is the radar wavelength).

INSTANTANEOUS FIELD-OF-VIEW (IFOV): (1) A term specifically denoting the narrow field of view designed into scanning radiometer systems, so that, while about 120° may be under scan, at any one instant only EMR from a small area is being recorded. (2) The field of view of a scanning radiometer with the scan motion stopped. See CELL.

- J -

- K -

Ka BAND: Radar wavelength region from 0.8 to 1.1 cm.

KINETIC TEMPERATURE: The internal temperature of an object, which is determined by the molecular motion, it differs from radiant temperature, which is a function of emissivity and internal temperature.

- L -

L-BAND: Radar wavelength region from 15 to 30 cm.

LAYOVER: Displacement of the top of an elevated feature with respect to its base on the radar image. The peaks look like dip-slopes.

LOOK ANGLE (radar): The direction of the look, or direction in which the antenna is pointing when transmitting and receiving from a perticular cell.

LUMINESCENCE: Light emission by a process in which kinetic heat energy is not essential for the mechanism of excitation. Electroluminescence is the production of light emission in a solid phosphor by the application of an electric field. This field stimulates electron or ion collision which causes energy of electrons or ions to be given up, resulting in light emission. Chemiluminescence results when energy, set free in a chemical reaction, is converted to light energy. The light from many chemical reactions and from many flames is of this type. Photoluminescence, or fluorescence, results from excitation by absorption of light. The term phosphorescence is usually applied to luminescence which continues after excitation by one of the above methods has ceased.

- M -

MICROWAVE: A very short EM wave; any wave between 1 meter and 1 millimeter in wavelength or 300 GHz to 0.3 GHz in frequency. The portion of the electromagnetic spectrum in the millimeter and centimeter wavelengths, bounded on the short wavelength sides by the far infrared (at 1 mm) and on the long wavelength side by very high-frequency radio waves. Passive systems operating at these wavelengths sometimes are called microwave systems. Active systems are called radar, although the literal definition of radar requires a distance-measuring capability not always included in active systems. The exact limits of the microwave region are not defined.

- N -

NEAR INFRARED: The preferred term for the shorter wavelengths in the infrared region extending from about 0.7 micrometers (visible red), to around 2 or 3 micrometers (varying with the author). The longer wavelength end grades into the middle infrared. The term really emphasizes the radiation reflected from plant materials, which peaks around 0.85 micrometers. It is also called solar infrared, as it is only available for use during the daylight hours.

- O -

- P -

P-BAND: A frequency band used in radar extending approximately from 30 to 100 cm. See RADAR

PANCHROMATIC: Used for films that are sensitive to broad band (e.g., entire visible part of spectrum) EMR, and for broadband photographs.

PARALLEL POLARIZED: Radar return pulse in which the polarization is the same as the transmitted pulse. Images recorded with parallel-polarized energy may be HH (horizontal transmit, horizontal return) or VV (vertical transmit, vertical return).

PERIOD: Time required for one oscillation. Thus it is the reciprocal of the frequency.

PHASE HISTORY (radar): A record of the phase difference between the transmitted signal and the received signal.

PICTURE ELEMENT: In a digitized image this is the area on the ground represented by each digital value. Because the analog signal from the detector of a scanner may be sampled at any desired interval, the picture element may be smaller than the ground resolution cell of the detector. Commonly abbreviated as pixel.

PIXEL: A contraction of picture element.

PULSE COMPRESSION (radar): The technique of reducing the effective length of a pulse of EMR by demodulating broadband information originally modulated on the pulse. A pulse may be frequency modulated (chirped) in which case pulse compression is sometimes called dechirping. PCM also may be used with compression achieved by suitable matched filtering or correlation.

PULSE LENGTH (radar): The length or duration of each pulse in a radar transmission.

PULSE LENGTH, EFFECTIVE (radar): Length of the compressed or dechirped pulse. A compression ratio of 30:1 means that the effective pulse length is 1/30th that of the original transmitted pulse. The effective pulse length is no shorter than the reciprocal of the bandwidth transmitted (approximately).

- Q -

Q-BAND: A frequency band used in radar extending approximately from 36 to 46 GHz.

- R -

RADAR: Acronym for RAdio Detection And Ranging. A method, system, or technique, including equipment components, for using beamed, reflected, and timed EMR to detect, locate, and (or) track objects, to measure altitude and to acquire a terrain image. In remote sensing of the Earth's or a planetary surface, it is used for measuring, and often, mapping the scattering properties of the surface.

RADAR BEAM: The vertical fan-shaped beam of EM energy produced by the radar transmitter.

RADAR, BRUTE FORCE or REAL APERTURE: A radar imaging system employing a long physical antenna to achieve a narrow beamwidth for improved resolution.

RADAR, COHERENT: A radar system in which the relative phase between the transmitted and received signals is compared and used.

RADAR CROSS SECTION: The ratio of power return in a radar echo to power received by the target reflecting the signal. It is equivalent to the intercepting area of an isotropic reradiator which would produce a radar echo at the sensor equal to that from the given target. Symbol, $\sigma°$.

RADAR MAP: A map produced by the application of radar techniques.

RADAR MILE: A time unit of 10.75 microseconds duration; the time it takes for the signal emitted by a radar to travel from the radar to a target one mile distant and return to the radar.

RADAR REFLECTIVITY: In general, the measure of the efficiency of a radar target in intercepting and returning a radar signal. It depends upon the size, shape, aspect, and the dielectric properties at the surface of the target. It includes the effects of not only reflection but also scattering and diffraction.

RADAR SHADOW: A no-return area extending in range from an object which is elevated above its surroundings. The object cuts off the radar beam, casting a shadow and preventing illumination of the shadowed area behind it.

RADAR, SYNTHETIC APERTURE (SAR): A radar in which a synthetically long apparent or effective aperture is constructed by integrating multiple returns from the same ground cell, taking advantage of the Doppler effect to produce a phase history film or tape that may be optically or digitally processed to reproduce an image.

RADIANCE: The accepted term for radiant flux in power units (e.g. watts) and not for flux density per solid angle (e.g. watts/cm^2 sr) as often found in recent publications.

RADIANT TEMPERATURE: Concentration of the radiant flux from a material. Radiant temperature is the product of the kinetic temperature multiplied by the emissivity to the one-fourth power.

RANGE (radar): The distance from the radar to a target; in sidelooking radar, the perpendicular to the azimuth (flight) direction.

RANGE STREAKING (radar): Narrow extensions of normal target image in the range direction.

RECTIFICATION: The process of projecting a tilted or oblique photograph onto a horizontal reference plane with the angular relation between the photograph and the plane determined by ground reconnaissance. Transformation is the special process of rectifying the oblique image from a multiple-lens camera to equivalent vertical images by projection onto a plane that is perpendicular to the camera axis. In this case, the projection is onto a plane determined by the angular relation of the camera axis and not necessarily onto a horizontal plane.

RECTIFICATION - DIFFERENTIAL: The process of removing the effects of tilt, relief, and other distortions from imagery by correcting small portions of the imagery independently.

REFLECTIVITY: A fundamental property of a material that has a reflecting surface and is sufficiently thick to be opaque. One may further qualify it as spectral reflectivity. The suffix (-ity) implies a property intrinsic with a given material, a limiting value.

RESOLUTION: The ability of an entire remote sensor system, including lens, antennae, display, exposure, processing, and other factors, to render a sharply defined image. It may be expressed as line pairs per millimeter or meters, or in many other manners. In radar, resolution usually applies to the effective beamwidth and range measurement width, often defined as the half-power points. For infrared line scanner scanners the resolution may be expressed as the instantaneous field-of-view, which see. Resolution also may be expressed in terms of temperature or other physical property being measured.

RESOLUTION CELL (Radar): The smallest element on the ground distinguishable on the image, usually consisting of the half-power beamwidth distance by the half-power pulse duration. As some systems use other discrimination techniques, however, different definitions may apply.

RETURN (Radar): EMR reflected by an object back to the antenna. Strong (bright): Strong or bright EMR returns that appear as light toned areas on imagery. Weak: Weak EMR returns which appear as a gray-toned area on imagery.

- S -

SCANNERS: (1) Any device that scans, and by this means produced an image. See SCANNING RADIOMETER. (2) A radar set incorporating a rotatable antenna, or radiator element, motor drives, mounting, etc. for directing a searching radar beam through space and imparting target information to an indicator.

SCANNING RADIOMETER: A radiometer, which by the use of a rotating or oscillating plane mirror, can scan a path normal to the movement of the radiometer. The plane mirror may move in various patterns--arcs, circles, lines. The mirror directs the incoming radiation to a detector, which converts it into an electrical signal. This signal is amplified to stimulate a device such as a tape recorder, or glow tube or CRT that can be photographed to produce a picture. When the system is moved forward at velocity V and at altitude H, a suitable V/H ratio may be established, so that consecutive scans are just touching. This is often called an IR-imager, but is only so restricted because of the optical materials used, all-reflective optics being as useful in the UV and visible regions. They may all be single--or multiple--band.

SCATTERING: (1) The process by which small particles suspended in a medium of a different index of refraction diffuse a portion of the incident radiation in all directions. (2) The process by which a rough surface reradiates EMR incident upon it.

SENSOR: Any device which gathers energy or EMR and presents it in a form suitable for obtaining information about the environment. Passive sensors, such as thermal infrared and microwave, utilize EMR produced by the surface or object being sensed. Active sensors, such as radar, supply their own energy source. Aerial cameras use natural or artificially produced EMR external to the object or surface being sensed.

SHADOW: Obscurity within the area or space from which direct EMR from a source is excluded by an interposed opaque body.

SIDELOOKING RADAR: An all weather, day/night remote sensor which is particularly effective in imaging large areas of terrain. It is an active sensor, as it generates its own energy which is transmitted and received to produce a photo-like picture of the ground. Also referred to as sidelooking airborne radar; abbreviation: SLAR.

SIGNATURE: Any characteristic or series of characteristics by which a material may be recognized. Used in the sense of spectral signature, as in photographic (color reflectance).

SLANT RANGE: Distance along a straight line from the radar to the object being illuminated.

SLANT RANGE IMAGE: An image in which objects are located at distances corresponding to their slant range distances from the flight path. Compare ground range image.

SPECULAR TARGET: Refers to a surface that is smooth with respect to the wavelength of incident radiation.

- T -

THERMAL ANOMALY: A pattern of thermal energy distribution which appears anomalous relative to adjoining areas. If linear, these patterns can be termed thermal linears, in the same context as structural linears.

THERMAL BAND: A general term for middle-infrared wavelengths which are transmitted through the atmosphere window at 8-13 micrometers. Occasionally also used for the windows around 3-6 micrometers.

THERMAL CAPACITY (HEAT CAPACITY): Product of density and specific heat (at constant pressure), a more regular and predictable parameter than thermal conductivity.

THERMAL CONDUCTIVITY: An intrinsic physical property of a substance, describing its ability to conduct heat as a consequence of molecular motion.

THERMAL DIFFUSIVITY: Governs the rate at which temperature changes within a substance, expressed in $cm^2 \cdot sec^{-1}$. The symbol is κ .

THERMAL INERTIA: Sometimes referred to as the thermal contact coefficient, it is a measure of the rate of heat transfer and is the product of thermal conductivity and thermal capacity. The reciprocal is often used instead, and is termed the "thermal parameter." Sometimes called conductive capacity.

THERMAL INFRARED: The preferred term for the middle wavelength ranges of the IR region, extending roughly from 3 micrometers at the end of the near infrared, to about 15 or 20 micrometers where the far infrared commences. In practice the limits represent the envolope of energy emitted by the earth behaving as a greybody with a surface temperature around 290°K (27°C). Seen from any appreciable distance, the radiance envelope has several brighter bands corresponding to windows in the atmospheric absorption bands. The thermal band most used in remote sensing extends from 8-13 micrometers.

SECTION G
Preservation/Packaging/Packing

G.1 Preservation, packaging and packing for Contract Line Items shall be in accordance with the best commercial practices.

SECTION H
Deliveries or Performance

H.1 The term of this contract shall commence on the effective date of this contract and shall end thirteen (13) consecutive months thereafter. Such term shall consist of a performance period of eleven (11) months for performance of CLIN 0001, technical effort, and two (2) months thereafter for preparation and submission of the Final Technical Report.

H.2 Deliveries, distribution, consignment and marking shall be made as follows:

Contract Line Item 0002 shall be delivered f.o.b. destination within the times specified in EXHIBIT A consigned and marked as follows:

SEQUENCE NUMBER	QUANTITY	CONSIGNMENT AND MARKING INSTRUCTIONS
A001	1/0 cy	W26AAQ U.S. Army Mobility Equipment Research and Development Command Procurement and Production Directorate ATTN: DRDME-PT-A Fort Belvoir, VA 22060 M/F: Contract No. DAAK70-78-C-0180
A001	1/0 cy	W26QKR U.S. Army Mobility Equipment Research and Development Command Fiscal Division, Office of the Comptroller Fort Belvoir, VA 22060 M/F: Contract No. DAAK70-78-C-0180
A001 A002 A003 A004	3/0 cys 5/0 cys 2/0 cys 15/1 cys	W26HAJ U.S. Army Engineer Topographic Laboratories Geographic Sciences Laboratories Fort Belvoir, VA 22060 M/F: Contract No. DAAK70-78-C-0180 ATTN: L.P. Murphy
A004	3/0 cys	W26HAJ U.S. Army Engineer Topographic Laboratories Survey and Engineering Division Fort Belvoir, VA 22060 M/F: Contract No. DAAK70-78-C-0180 ATTN: STINFO
A004	~~2/0 cys~~	S, 47031 Defense Documentation Center ATTN: DDC-TCA Cameron Station, Building 5 Alexandria, VA 22315

THERMAL RADIATION: The electromagnetic radiation emitted by a hot blackbody, such as the filament of lamp.

TONE: Each distinguishable shade variation from black to white.

TRANSMITTANCE: The ratio of the radiant energy transmitted through a body to that incident upon it. The suffix (-ance) infers a property of that particular specimen.

- U -

- V -

VISIBLE RADIATION: EMR of the wavelength interval to which the human eye is sensitive, the spectral interval from approximately 0.4 to 0.7 micrometers (4000 to 7000 Å).

- W -

- X -

X-BAND: Radar wavelength region from 2.4 to 3.8 cm.

- Y -

- Z -